THE DEVELOPMENT OF WIRELESS TO 1920

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THE DEVELOPMENT OF WIRELESS TO 1920

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THE DEVELOPMENT OF WIRELESS TO 1920

Edited by
George Shiers

With an Introduction by
Elliot N. Sivowitch

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ELLIOT N. SIVOWITCH

A Technological Survey of Broadcasting's "Pre-History," 1876-1920

Although the JOURNAL OF BROADCASTING *commemorated broadcasting's 50th anniversary more than a decade ago (see the Fall, 1959 issue), it was not until 1970 that the golden anniversary of American broadcasting was celebrated nationwide. Yet, before the initial broadcasts of KDKA and WWJ in 1920, there was almost another half-century of technological development. This technological base consisted of experimental work in both wired and wireless telephony, and included many "dead ends" as well as many developments that led to the fruition of broadcasting.*

In the following article, Elliot Sivowitch, of the Division of Electricity and Nuclear Energy of the Smithsonian Institution, covers the high points of the "pre-history" of broadcasting, with emphasis on developments in the United States prior to 1920. A forthcoming issue of the JOURNAL *will feature a companion article, tracing developments of the first decade of broadcasting itself through analysis of the history of significant early stations, which is being prepared by Joseph E. Baudino of the Westinghouse Broadcasting Company.*

IN the period prior to 1876, the telegraph, in its various forms, was the principal rapid news conveyor throughout the world. The transmission of information in this manner can be construed as "broadcasting" only if one interprets the usual definition ("the dissemination of radio communications intended to be received by the public, directly or by the intermediary of relay stations") in the sense of "wide dissemination of information, not necessarily at the same point in time." For the purposes of this paper, we will use a very broad definition and will include experiments that might more properly be related to point-to-point communication than to current definitions of broadcasting.

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Wired Broadcasting

The telephone's introduction in 1876 forced a revolution in communication capability with wide ranging social and economic implications. Not only could more words per minute be transmitted, in both directions, but anybody could use the telephone without special training in code. This magic of voice transmission over wire led 19th century innovators to serious thoughts concerning the transmission of news and entertainment simultaneously and instantaneously to multiple receiving points. Although broadcasting by wire was hampered by equipment limitations with regard to fidelity and amplification, the idea was sufficiently intriguing to be explored by engineers both in this country and in Europe. Commercial development, however, was considerably greater abroad, where sound "rediffusion" (analogous in many ways to CATV) still exists in many places.

The beginnings of wired broadcasting can be traced to a "pre-telephone" transition period after 1860, when a number of experimenters were developing methods for transmitting musical tones over telegraph wire lines. These activities may have culminated in the work of Elisha Gray, who conducted several tests of "electroharmonic" broadcasting to audiences in 1874 and 1875.[1] Following a successful demonstration by Alexander Graham Bell of the speaking telephone at the 1876 Philadelphia Centennial Exposition, the possibilities of using it as a broadcast instrument were apparent. In the Fall of 1876, experimental "concerts" were transmitted over wire line by Bell from Paris to Brantford, Ontario, utilizing a "triple mouthpiece" telephone transmitter to accommodate several soloists. From 1876 through 1880 a variety of transmissions were conducted, both in this country and in Europe. The carbon transmitter, co-invented during this period by Edison, David Hughes and Emile Berliner, enormously increased the power output of the telephone. In 1881, Clement Ader, in France, conducted intensive investigations of wired stereophonic broadcasting at the Paris Electrical Exposition, and by 1895 various European Opera Houses were equipped with either stereo or monophonic telephone systems. In 1893 a commercial broadcasting system called the Telefon-Hirmondo (Telephonic Newseller) began operation in Budapest, Hungary, and shortly afterward the Electrophone Company started service in London. The Budapest operation was a highly sophisticated system that provided regular news and music programming up

to 12 hours per day.[2] Although the European activities were reasonably successful, the United States did not see similar developments until the Cahill Telharmonium broadcasts more than a decade later.[3] However, there were frequent occasions here of subscribers being "wired up" for specific church service broadcasts or special events. Of more than usual significance was the broadcasting of Congressional and local election returns by the Chicago Telephone Company on Nov. 6, 1894. It was estimated that more than 15,000 persons were reached by this novel transmission method.[4]

Loomis-Ward Aerial Conduction Telegraph

19th century thoughts on broadcasting were not limited to land line experimentation. On April 30, 1872, William Henry Ward of Auburn, New York, received a patent for a telegraphic tower (No. 126356) that might be said to embody the earliest conception of transmitting signals by wireless from a single antenna to a multiplicity of receiving aerials. In the wording of the patent:

> Different towers may be erected on the different continents, and if they are all what is technically called hooked on—that is to say, connected to the earth—a signal given at one tower will be repeated at all the towers, they being connected with each other by the aerial current.

No mention of the telephone, of course, at this early date. However, a word of caution should be mentioned here. The "wireless" system described is that of *conduction transmission,* a technique developed by telegraph engineers after 1838 when it was discovered that two wires were not necessary to complete a circuit. One could be eliminated and a return made through the ground. All sorts of intriguing possibilities were then thought of, including the idea of communicating across bodies of water. The particular technique which Ward envisioned involved the elimination of both wires, the use of the ground and bodies of water as a substitute for one wire, and the "conducting atmosphere" in place of the other wire. The inspiration for communicating through the atmosphere in this manner appears to have developed from observations of the effect of the aurora borealis on telegraph lines. Auroral storms created all sorts of havoc on domestic telegraph circuits including the freak ability to send messages over wire line with induced currents, entirely eliminating the need for batteries. If such electricity in the upper atmosphere could be harnessed,

what a tremendous boon for global communications! We have no evidence however, that Ward actually built a tower (which, by the way, looks in the patent application drawing very much like the modern space-satellite communications antenna in Andover, Maine—although, of course, operating on entirely different principles) and conducted experiments. Ward was principally an independent inventor in mechanical technology, with a concentration in railway car coupling devices. However, during the 1850s and 60s he developed a rather sophisticated semaphore signalling system for maritime communication, and published a book describing his coded symbols in some detail.[5] Sometime during this period he appears to have made the acquaintance of Mahlon Loomis and possibly was influenced by the latter's thoughts on conduction telegraphy. Loomis (1826-1886), a Washington D. C. dentist, was the principal 19th century exponent of aerial conduction communication. Loomis' thoughts on wireless transmission date back to the great auroral storm of 1859 which was particularly vexing to telegraph operators in the Northeast United States.[6] Loomis seems to have conducted several tests in the Blue Ridge and Catoctin mountain ranges of Virginia and Maryland in the 1866-72 period but a detailed account of the equipment used and persons present is lacking. However, he obtained considerable support in Congress and probably would have received an appropriation had not the financial panic of 1873 struck.[7] The most important question, of course, from the engineering point of view, is whether the Loomis-Ward system could have worked in terms of the design theory assigned to it. The answer is "no," with the qualification that under certain unusual conditions in the ionosphere, some deflection of the receiving galvanometer might be noticed. What is more likely is that Loomis radiated some electromagnetic energy from discharges of atmospheric electricity at the transmission end. Again, firm evidence is not at hand. Loomis was granted a patent for his system July 30, 1872.[8]

Although the aerial conduction scheme passed into obscurity, systems involving conduction through the ground appeared over the next few decades and have been revived in modern times. These, however, were viable systems without any question, though only over limited distances. So far as our broadcasting story is concerned, however, ground conduction becomes intertwined with certain other related phenomena in the developing telephone technology.

We mentioned earlier the experimental telephone "concerts" promoted soon after the instrument was introduced. In 1877, a telephone "broadcast" was made from New York City to Sarasota Springs, New York, using a newly developed Edison transmitter. The musical programming was heard accidently in both Providence and Boston due to electrical leakages between adjacent sets of wires on trunk lines north of New York City. Although conduction leakage through the ground was the principal cause, *induction* through the air also was involved. Within both phenomena lay mechanisms for a new mode of communication: suppose one were to purposely cause induction of energy with large loops of wire, or conduction with stakes buried in the ground—would not a useful communication device result? This line of development appealed to several late 19th century personalities, though considerable thought toward wireless techniques of this general type was in evidence even prior to 1850.[9] The crucial point to remember, however, is that the scientific base for induction-conduction communication was a natural outgrowth of conventional telegraph and telephone technology, and was not directly related to the Hertz-Marconi approach to wireless. The latter method employed *radiated* waves of high frequency which had the capability some distance. However, there are certain interrelationships between these various systems which we will describe in the following critical review of the work of one early "wireless broadcaster."

Nathan Stubblefield

Nathan B. Stubblefield (1860-1928), of Murray, Kentucky, was a self-taught tinkerer-experimenter. He is more in the tradition of Daniel Drawbaugh than Edison or any of the university savants.[10] However, he has a persistent vision of the success of his method of communication and influenced several businessmen to finance commercial exploitation. His first claim to fame, however, came via local "acoustic telephone" hookups in Murray circa 1890.[11] Following investigations into induction and conduction telephony, he developed several types of apparatus and performed some public demonstrations prior to 1900. In March 1902 he succeeded in transmitting speech from a boat in the Potomac River to shore-based receivers. Inspired by this operation he boasted of the practicability of sending simultaneous messages from a "central distributing station" and of conveying the "general transmission of news."[12] However, commercial thoughts

were directed toward point-to-point communication. The Wireless Telephone Company of America was formed and an active stock promotion plan put into operation. Although the stock prospectus was quick to point out the virtues of a cheap wireless system versus the expensive Bell Telephone lines, the fact of the matter was that induction/conduction telephony was too marginal in distance capability to offer any serious competition to Bell. The Gordon Telephone Company of Charleston, South Carolina, did purchase some equipment to communicate with off-shore islands, but this was about the extent of the operation's success.[13] Stubblefield became disillusioned with the stock promotion schemes of his financiers and withdrew to seclusion in his workshop. He did receive identical United States and Canadian patents in 1903 for the induction system[14] and an examination of the basic principle may prove useful.

A battery and telephone were to be connected in series with a very large coil of wire (i.e. transmitting "antenna"). Upon speaking or singing into the microphone, audio frequency currents would flow in the loop, and an alternating current induction field would form in the vicinity of the "antenna." A pickup-loop mounted atop a moving vehicle would act as the receiving aerial and feed a simple telephone receiver. Now here is the critical point: most of the energy in the induction field is contained in the vicinity of the transmitting loop. The field, however, is varying at an audio-frequency, so far as this is concerned it obeys the same law as any varying field in space, regardless of frequency. Why isn't this radio? It turns out that we can determine from electromagnetic theory that there are three components of a varying electromagnetic field in space, one whose electric field intensity varies inversely as the cube of the distance, $1/R^3$ (static field), one inversely as the square of the distance, $1/R^2$ (induction field), and one inversely as the distance, $1/R$ (radiation field). Some energy is *radiated* away from the antenna at any frequency, but at *low frequencies* (i.e., voice and music) most of the energy is confined to the vicinity of the wire.[15] The induction field is the principal component of the Stubblefield system, and this limited the transmission range of the system to something less than three miles. (This is not to be confused with the case where we superimpose voice or music on a higher radio frequency and make full use of radiation capability, as in modern broadcasting.)[16]

The mathematical processes and field theory outlined above were known in 1908, but at this stage of the game, the fine points of difference between the various wireless systems were not appreciated; after Marconi's work became known in this country many were quick to point out that Stubblefield had transmitted voice (not just Morse Code) via "wireless" as early as 1892.

Edison, Dolbear, Thomson and Stone

More than a decade before Stubblefield's first experiments, there was a line of development in which double-winding induction coils similar to the types employed in early telephone work and in physics laboratories were utilized. In some circuit configurations an induction field would predominate, and in others radiation capability existed, but the state of the art was such that most electricians and physicists failed to recognize the capability of the induction coil in the production of high frequency waves. Several persons were on the fringe of exciting discoveries but "missed the boat" by narrow margins. Included in this group were Thomas Edison and Elihu Thomson, who conducted a variety of investigations in the 1870s in which electrical sparks produced by a generator could be detected at a distance.[17] Only Heinrich Hertz, in Germany, really understood what was going on. His brilliant experimental proof of Scottish physicist James Clerk-Maxwell's theoretical predictions took place in 1888. However, the most significant work from the wireless telephone standpoint was performed by Amos Emerson Dolbear, Professor of Physics at Tufts College.[18] Dolbear, in the early 1880s, conducted a number of experiments with induction coils, carbon and condenser telephone transmitters, and batteries in a wireless set-up with grounded wires at both ends of a communications link. The system was fully described in the *Scientific American* of Dec. 11, 1886 and a patent was awarded (No. 350299). Transmission range (mostly induction field) was limited to something less than one mile. Following the development of true radiation wireless telegraphy more than a decade later, it was realized that Dolbear's circuit configuration created a borderline situation in which he probably radiated electromagnetic energy to greater distances but lacked a suitable detector. The Dolbear patent was later used by the DeForest radio interests in an attempt to prove priority over Marconi.[19]

By the mid-1890s a variety of experimentation in induction telegraphy and telephony was in evidence. However, the concept of modulating a high frequency carrier wave with voice perhaps can be ascribed to John Stone Stone who, in 1892, utilized both induction coils and alternating current generators in experiments designed by AT&T to communicate by telephone with ships at sea. Although the inspiration for this series of investigations came from the work of Hertz and Tesla, and preceded Marconi by several years, Stone fell short of "inventing" radio partly by reason of the aforementioned confusion of induction with radiation, and partly by lack of appreciation of the need for such appliances as antennas and modulation detectors.[20]

Reginald Fessenden

The credit for a major breakthrough in superimposing voice or music information on a high frequency "carrier" goes to Reginald A. Fessenden (1866-1932), whose persistence along these experimental lines culminated in what many regard as the first broadcast using a reliable continuous wave generator (the high frequency alternator) from Brant Rock, Massachusetts, on Christmas Eve, 1906.

The high frequency alternator essentially was a type of alternating current generator that produced "continuous waves" in the radio frequency range. The term "high frequency" is a misnomer by modern standards, since the device operated under 100 kHz. Although developed by Elihu Thomson and Nikola Tesla in the late 1880s, Fessenden probably was the first to apply it to radio communication.

Fessenden became interested in wireless during the embryo period of the 1890s, but realized very soon that conventional spark oscillators used for radiotelegraphy created too high a distortion level to make the radiotelephone practical. However, he conducted some tests along these lines in December, 1900, at Rock Point, Md. (Cobb Island, 50 miles south of Washington, D. C.) where distances up to one mile were bridged.[21] He seems not to have had a really adequate detector on the receiving end, but the system was patented in 1902 (No. 706747) and constitutes the earliest registered invention in the United States for a radiotelephone system employing Hertzian waves. Some commercial radiotelephone sets using the spark system were marketed by Fessenden.

At the turn of the century, another development occurred which proved crucial for the growth of experimental broadcasting. This was the application of the high frequency arc to wireless. The oscillating arc was basically a circuit arrangement that included two carbon electrodes activated by high voltage and shunted by suitable inductance and capacitance. Investigated by Elihu Thomson in 1889, it was not until further work after 1900 by William Duddell in England and Valdemar Poulsen in Denmark that frequencies high enough for radio transmission could be realized. Although the arc did produce "continuous waves" and was a favorite of other experimenters, Fessenden felt uncomfortable with it because of its high distortion level and instability.[22] As a result, he asked Charles Steinmetz of the General Electric Company to construct a 10,000 cycle alternator for him that would have some capability for modulation with voice or music information. Tests with this machine were made at the Washington, D. C. laboratory of the newly formed National Electric Signalling Company in 1905. Results were encouraging enough to construct a higher frequency machine for the use at NESCO's Brant Rock, Massachusetts installation. The engineering team at Schenectady was headed by E. F. W. Alexanderson, a talented young Swedish electrical engineer. An alternator was delivered to Fessenden in 1906, and after many technical difficulties made ready for its debut. On Nov. 21, 1906, a variety of scientific dignitaries, including Greenleaf W. Pickard and Elihu Thomson, witnessed tests in which speech was successfully transmitted 11 miles between Brant Rock and Plymouth, Mass.[23] A phonograph was on hand and was used to transmit music over the airwaves. On Christmas Eve, 1906, Fessenden and his group at Brant Rock presented a program of varied content for the holiday occasion; this was advertised to ship operators of the United Fruit Co. three days in advance. A similar schedule was presented on New Year's Eve. Ship reports of reception came from points as far away as Norfolk and the West Indies. The programming was described by Fessenden:

> First a short speech by me saying what we were going to do, then some phonograph music . . . the music on the phonograph being Handel's "Largo." Then came a violin solo by me, being a composition by Gounod called "O, Holy Night," and ending up with the words "Adore and be still" which I sang one verse of, in addition to playing the violin, though the singing, of course, was not very good. Then came the Bible text, "Glory to God in the highest and on earth peace

> to men of good will," and we finally wound up by wishing them a Merry Christmas and then saying that we proposed to broadcast again New Year's Eve.
>
> The Broadcast on New Year's Eve was the same as before, except that the music was changed and I got someone else to sing. I had not picked myself to do the singing, but on Christmas Eve I could not get any of the others to either talk, sing or play and consequently had to do it all myself. On New Year's Eve one man — I think it was Stein — agreed to sing and did sing, but none of the others either sang or talked.[24]

NESCO continued experimental work on the radiotelephone in July, 1907, and obtained distances up to 180 miles. The following excerpt from the log of wireless enthusiast Francis Hart shows the description of the transmission as received in the New York harbor area on Feb. 11, 1908, at 1:16 p.m.:

> Wireless phone at Jamaica and other must be at Brant Rock, Mass. Phone very clear except for a rasping noise that mingles with the voice . . . I managed to get the following and could probably have obtained more except for "9" and etc.
> "How's that now" "open up a little more"
> "You came in louder than that yesterday"
>
> Could hear music as clear as voice from weaker station but couldn't make out words from other station although they came in fair.[25]

Although NESCO's wireless telephone activities continued for a time, the company ran into economic and administrative difficulties. The Bell System was quite impressed with Fessenden's wireless telephone, but AT&T suffered a major reorganization following the financial panic of 1907 and interest cooled. Fessenden and his financial backers also were on poor terms for several years, and the inventor was forced to leave the company in 1911. The following year NESCO went into receivership, though the organization continued in research and development activities until its purchase by Westinghouse in 1921. The alternator, for all its wizardry in wireless telephony, was too cumbersome a machine and the engineering fraternity preferred to endure the higher distortion level in the more portable Poulsen arc. The alternator's significance in radiotelegraphy would overshadow other use, as would its political effect in the battle over control of the early radio industry in the period during World War I and thereafter.

DeForest and the Arc Radiotelephone

Of all the members of the early wireless engineering fraternity, perhaps Lee DeForest, more than any other, had some vision of the broadcasting potential of the wireless telephone. Although possessing a Ph.D. in physics from the Sheffield School at Yale (1896), DeForest basically was an experimental electrician in the tradition of Edison rather than a mathematician such as Maxwell or Kelvin. He foresaw, at an early date, the application of the high frequency arc to modulated radio frequency transmission. In December, 1906, he succeeded in transmitting voice across his laboratory room in the Parker Building (19th Street and 4th Avenue, Manhattan) to a receiver employing a vacuum tube detector.[26] A number of experimental broadcasts were made early in 1907, and were picked up by ship operators in New York harbor.

In the summer of 1907 DeForest and his assistant, Frank Butler, went to Put-in-Bay on Lake Erie to report the Interlakes Association regatta from a radiotelephone installation aboard the *Thelma.* The Navy Department watched these activities closely and became aware of the potential of voice transmission as a tactical communication device. It should be noted, incidentally, that to promote this new invention the DeForest Radio Telephone Company was organized earlier in the year and a subsidiary, the Radio Telephone Company, was formed for the purpose of developing DeForest's patents. In September, the Navy ordered two complete transmitting and receiving units for installation aboard the *U.S.S. Connecticut* and *U.S.S. Virginia.* Trials were held in Cape Cod Bay, and were so successful that the Navy ordered another two dozen sets for installation aboard Admiral Evans' "Great White Fleet," which was scheduled to depart for an around-the-world cruise on December 16. DeForest and his co-workers slaved night and day to get the equipment ready. Due to hasty procedures and other technical problems, some of the transmitters were inoperable, but several vessels, including the *U.S.S. Ohio,* continued to experiment for the duration of the voyage.[27] By January, 1908, the arc aboard the Ohio was made sufficiently stable to operate for several hours at a time. Radic-telephone broadcasts were made to the assembled U. S. and Brazilian fleets and later to British and Chilean vessels as the expedition moved along the South American coastline. In April, while the fleet anchored at Long Beach, Calif.,

the radio crew aboard the Ohio procured a phonograph and proceeded to entertain local radio operators. The inspiration for these broadcasting activities may have come from some of DeForest's tests at the Brooklyn Navy Yard prior to the sailing of the Connecticut and the Virginia for New England waters. It was here that contralto Madame von Boos Farrar sang "I Love You Truly" and "Just-a-Wearyin' for You" to the radio operators in the port. On April 23, 1908 the DeForest Company gave a banquet in Los Angeles for the Fleet wireless telephone crew. Roscoe Kent, one of DeForest's assistants, casually mentioned to the assembled group that this was the "first meeting of radio broadcasters."

Admiral Evans' fleet continued its cruise to the Orient where additional radiotelephone programs were "beamed" to the Japanese Fleet at Yokohama harbor, and upon continuation of the journey eastward similar activities were conducted near ports in Ceylon, Arabia, Egypt, Greece, Turkey, and Gibraltar. Broadcasts also were made to several ocean-going liners. Upon return to the Brooklyn Navy Yard in March, 1909, the equipment was placed in storage. The Navy was not again equipped for wireless telephony until 1917.

A corollary episode was taking place about this time in New York City that has some bearing on our story. Dr. Thaddeus Cahill, a scientist from Holyoke, Mass., demonstrated a sophisticated musical tone system before a meeting of the New York Electrical Society in September, 1906. The new device was called a "Dynamophone" or "Telharmonium," and consisted of a bank of alternating current generators controlled to give musical tones of varying combinations. The Cahill Telharmonium Company occupied a large building at 39th Street and Broadway. The musical transmissions were played on an organ-type console and fed from the generating plant to distribution lines leading to various halls and restaurants where receiving telephonic speakers were installed. The system can well be termed the first serious venture into a background music system in this country. However, owing to the Bell Telephone Company's reluctance to give permission for use of conventional telephone lines (fearing damage to equipment), plans to extend the service to individual subscribers were seriously hampered. The Cahill Company was intrigued by DeForest's wireless telephone and gave permission for a trial broadcast of Telharmonium music over the air waves.[28] The programs took place in February and March of 1907 but apparently were not extended

further. One can only conjecture that the audio quality left much to be desired. DeForest at this time was using Poulsen's version of the arc, but attempting to improve performance by substituting steam for hydrogen.

While Admiral Evans' "Great White Fleet" was on its round-the-world trip, DeForest traveled to Europe and conducted several spectacular wireless telephone demonstrations from the Eiffel Tower, Paris, in Spezia, Italy and in Portsmouth harbor, England. Upon return to the United States, he occupied himself with several matters relating to his equipment manufacturing activities, though the radiotelephone was still operated almost daily. He returned to an intense interest in musical broadcasting during the winter of 1909. Then he made the acquaintance of Andreas Dippel, assistant director of the Metropolitan Opera House and, outlining the past experiences with the Telharmonium and phonograph, persuaded the management to allow experimental broadcast of grand opera. The principal event occurred January 13, 1910, when *Cavalleria Rusticana* and *I Pagliacci* were transmitted, with several famous soloists including Ricardo Martin and Enrico Caruso. This activity actually was conducted in conjunction with the National Dictograph Company, whose president Kelley M. Turner had designed a new "acousticon" pick-up microphone for stage use. The tests were arranged both to determine the feasibility of broadcasting opera to telephone subscribers over wire line, and to check out the similar capability of wireless. Although the broadcasts were reasonably successful, and repeated again later with staff from the Manhattan Opera Company, one can safely conclude that limitations in audio fidelity and instability problems with the arc made commercial exploitation premature. The Radio Telephone Company became the victim of early stock promotion schemes and went bankrupt in 1911. DeForest then transferred his activities to the West Coast and went to work for the Federal Telegraph Company.

In 1915, the American Telephone and Telegraph Company conducted significant tests in radiotelephony at the site of Navy station NAA, Arlington, Va. Using banks of vacuum tubes in oscillator and modulator circuits, signals were transmitted across the Atlantic and were heard as far away as Honolulu.[29] Possibly with this event as the stimulus, DeForest picked up his broadcasting activities again, this time from High Bridge in the Bronx. A new company backed the venture, the DeForest Radio Telephone and Telegraph Company, bol-

stered with 5 years of advance in technology and a firmer patent position. Of particular interest was the manufacture of "oscillion" transmitting tubes, now being produced with power ratings up to 125 watts. DeForest installed a transmitter at the Columbia Gramophone Building on 38th St. and began daily broadcasts of phonograph music with the Columbia company as the sponsor. The transmitting site was later moved back to the High Bridge tower. On election night, November 7, 1916, DeForest broadcast the Hughes-Wilson election returns for some six hours—erroneously proclaiming at 11p.m. (as did several newspapers) that the winner was Charles Evans Hughes.[30]

The U. S. entry into World War I shut down all non-Government radio operations in 1917, but two years later DeForest set up operations again at the High Bridge location with call letters 2XG.[31] Phonograph records this time were supplied by the Brunswick-Balke-Collender Company, which acted as sponsor. Richard Klein, of the DeForest sales organization, was the program director. In December, 1919, concert singer Vaughn de Leath appeared as soloist and made several broadcasts. The station later moved its facilities to the World Tower Building at 46th and Broadway to utilize better antenna facilities, but DeForest neglected to get a Government permit for the new location and the operation was ordered closed by the district federal radio inspector. This, together with other vexing legal troubles, prompted the inventor to once again head West. In San Francisco, the High Bridge transmitter was re-installed in the California Theater Building and daily broadcasts were made with Herman Heller's orchestral group. From this point on the story of the DeForest broadcasting activities becomes involved with the attempt of a group called the Radio News and Music Company to interest newspaper owners in the purchase of DeForest radiotelephone transmitters. The Detroit *Daily News* did so, and herein lies the start of the story of WWJ, whose predecessor 8MK began operation August 20, 1920, an event that will be recounted in a future article in the JOURNAL OF BROADCASTING.

West Coast Radiotelephony

The critical role of the high frequency arc and alternator in the growth of radiotelephony has been stressed. These devices were "continuous wave" generators, and were only reliable tools for voice modulation techniques prior to development of the vacuum tube oscillator. However, Marconi-type "damped wave" transmitters didn't necessarily preclude telephony if distortion caused by the spark ir-

regularity and low spark frequency could be minimized. In practice this was difficult to do, though Fessenden, as we have indicated, made some efforts in this direction.

In 1902, an amateur operator from San Francisco, Francis McCarty, began to experiment in spark telephony with a view toward development of a commercial system. The Henshaw brothers, influential bankers of Oakland, California, were persuaded to invest some capital in the new venture. However, McCarty was fatally injured in a motorcycle accident in 1906, and the project was temporarily interrupted pending the search for new engineering advice and leadership. In 1908, Cyril Elwell, an electrical engineering student at Stanford, was persuaded to join the McCarty Wireless Telephone Co. as a consultant.[32] He proceeded to set up experimental broadcasting with a phonograph supplying the program content. Elwell realized that the McCarty system worked best when the transmitter spark gap was so narrow that the system operated as a quasi-arc, providing nearly continuous waves. Experiments were continued from the Company's Palo Alto laboratory until early 1909. At that time, Elwell advised the management that it would be useless to play around further with spark gaps, and that the Poulsen arc held the real future for wireless engineering. Elwell discovered that the U. S. patent rights for Poulsen's invention had not yet been granted. An inquiry to the Danish inventor revealed that something in the neighborhood of one-quarter million dollars was considered the proper "ball-park" figure. The Henshaw brothers were, however, disinterested in putting further investment capital into such new and uncertain ventures, and sold the laboratory to Elwell for a low figure. The account of how a young Stanford graduate then proceeded to buy the U. S. rights to a significant invention is a fabulous story that we have insufficient space to treat here; suffice it say that Elwell formed the Poulsen Wireless Telegraph and Telephone Co. with support from the Stanford faculty and a certain amount of good fortune perhaps possible only in the first decade of the 20th century. A considerable amount of experimental broadcasting and point-to-point radio telephony with stations at Stockton and Sacramento formed the principle wireless telephone "menu" of the day, with much of this work done for stock selling and promotion purposes. However, as with the alternator, the Poulsen arc's principal use would come with radio telegraphy, and Elwell's successor company, the Federal Telegraph Co., catered primarily to customers desiring high-powered telegraphic communication.

In the meantime, however, the "fall-out" from the arc technology spread to other experimenters. San Jose's Charles Herrold was the principal West Coast exponent of wireless entertainment in the pre-1920 era.[33] In Seattle, Washington, William Dubilier performed a variety of "broadcasts" in 1911-1912 using modulated sparks and arcs. Back in the East, A. Frederick Collins of Philadelphia, under the auspices of the Collins Wireless Telephone Co., marketed equipment of short range capability, but including spark and arc oscillators. In New York City, Alfred Goldsmith, Professor of Electrical Engineering at CCNY, operated a broadcasting station at the College in the 1912-14 period under call letters 2XN.[34]

The above description of arc/spark events prior to 1914 indicate that quite a bit of activity was taking place apart from the work of Fessenden or DeForest, though these two personalities were still the most prominent on the wireless telephone scene. Between 1912 and 1915 there were some critical advances in electronic engineering, including the audio frequency amplifier (DeForest), regenerative amplifier and feedback oscillator (DeForest and E. H. Armstrong), and vastly improved high-vacuum triode radio tubes (Bell Laboratories and General Electric).

Sarnoff and the "Radio Music Box"

Early in 1914, the American Marconi station in New York's Wanamaker Building was refurbished with a low power vacuum tube transmitter for experimental broadcasting of phonograph music. David Sarnoff, Contract Manager for the Company, had sailed aboard the *S.S. Antilles* for New Orleans to attend a convention of Railway Telegraph Superintendents. By advance scheduling, the Wanamaker station was tuned in while the vessel was about 60 miles away from New York. This incident appears to have influenced the young executive, and, coupled with some fast breaking technical developments (such as E. H. Armstrong's feedback circuit and the Bell Company's radiotelephone tests) led to the famous "Radio Music Box" memorandum of Sept. 30, 1915, addressed to Edward J. Nally, Vice President and General Manager of the Marconi Wireless Telegraph Company of America:

> I have in mind a plan of development which would make a radio a "household utility" in the same sense as the piano or phonograph. The idea is to bring music into the house by wireless.

> While this has been tried in the past by wires, it has been a failure because wires do not lend themselves to this scheme. With radio, however, it would seem to be entirely feasible. For example, a radiotelephone transmitter having a range of, say, 25 to 50 miles can be installed at a fixed point where instrumental or vocal music or both are produced. The problem of transmitting music has already been solved in principle, and therefore all the receivers attuned to the transmitting wavelength should be capable of receiving such music. The receivers can be designed in the form of a simple "Radio Music Box" and arranged for several different wavelengths, which should be changeable with the throwing of a single switch or pressing of a single button.
>
> The "Radio Music Box" can be supplied with amplifying tubes and a loudspeaking telephone, all of which can be neatly mounted in one box. The box can be placed in the parlor or living room, the switch set accordingly, and the transmitted music received. There should be no difficulty in receiving music perfectly when transmitted within a radius of 25 to 50 miles. Within such a radius, there reside hundreds of thousands of families; and as all can simultaneously receive from a single transmitter, there would be no question of obtaining sufficiently loud signals to make the performance enjoyable. The power of the transmitter can be made 5 kilowatts, if necessary, to cover even a short radius of 25 to 50 miles, thereby giving extra-loud signals in the home if desired. The development of a small loop antenna to go with each "Radio Music Box" would likewise solve the antenna problem.[35]

A typical transmitter of 1915 or 1916 would be a vacuum tube oscillator (or a Poulsen arc, if one could stand the noise) with necessary speech modulation equipment. The home listener could use a simple crystal set or perhaps one of the single-tube receivers then available to amateur radio operators.

An obvious question would be: If all the necessary appliances for radio broadcasting were here in 1915, why wasn't broadcasting itself?

As so often happens with benefit of hindsight, we may be able to deduce more from the evidence than really applies to the situation. It would seem, however, that Sarnoff's proposal was perfectly reasonable, considering the state of the art as well as the past experience of DeForest and the Bell System engineers not to mention the full gamut of wired and wireless telephony development since Alexander Graham Bell's demonstrations of the telephone 40 years earlier.

The answer, it would seem to us, is two-fold: (1) A lack of appreciation of the entertainment and information capability of the

radio-telephone ("the time isn't ripe yet" cliche); and (2) a turbulent patent situation leading to all sorts of manufacturing difficulties.

In September, 1916, the courts ruled that DeForest had infringed the two-element Fleming Valve patent, and the Marconi Company had infringed the three-element DeForest "Audion" tube patent. Nobody could manufacture triodes—absolutely essential for vacuum-tube transmitters and for tube-type receivers. Then the General Electric Company and AT&T became involved in patent interferences on the "feedback circuit" used with the triode.[36] Although there was a Navy-inspired truce for the purpose of aiding the war effort during World War I, this paralysis was not really resolved until the post-war cross-licensing agreements between the industry giants. Then broadcasting really had a chance to flourish.[37]

Footnotes

[1] E. N. Sivowitch, "Musical Broadcasting in the 19th Century," *Audio* (June, 1967), 19-23.

[2] Sivowitch, *Op. Cit.;* David L. Woods, "Semantics versus the First Broadcasting Station," JOURNAL OF BROADCASTING, XI:3 (Summer 1967), 199-207.

[3] *Infra* (Section on DeForest). The Telharmonium was an "electrical music" generator.

[4] *Electrical Review,* 25 (Nov. 21, 1894), 259.

[5] William H. Ward, *Ward's Code of Signal Telegraph for Ocean Marine Service* (Auburn N.Y.: W. H. Ward, 1858).

[6] Loomis Notebook, Mahlon Loomis Papers, Manuscripts Division, Library of Congress.

[7] Thomas Appleby, *Mahlon Loomis: Inventor of Radio.* (Washington, D. C.: Loomis Publications, 1967) 101-104.

[8] No. 129971. Appleby feels that Loomis definitely radiated a signal with his apparatus, and received it with some type of rectifier action or magnetic detector effect in the galvanometer circuit.

[9] Samuel F. B. Morse had conducted experiments as early as 1842. See J. J. Fahie, *A History of Wireless Telegraphy.* (New York: Dodd, Mead & Co., 1902).

[10] Drawbaugh was a mechanic from Eberlys Mills, Pennsylvania, who worked on telephonic devices in the 1860s and 70s. He lost a legal decision to Bell by a very close margin. See Warren J. Harder, *Daniel Drawbaugh: The Edison of the Cumberland Valley.* (Philadelphia: University of Pennsylvania Press, 1960).

[11] The "acoustic telephone" was essentially a "tin-cans-and-string" telephone for house-to-house communication. Believe it or not this type of device had some commercial application during the same time span as the first electric telephones, circa 1875-1895. Stubblefield had a patent on his device.

[12] Tom Hoffer, "Nathan B. Stubblefield and His Wireless Telephone." JOURNAL OF BROADCASTING (forthcoming).

[13] Prospectus, Wireless Telephone Company of America, Clark Collection CWC 4-3340A. (See "note on sources" at end of footnotes).

[14] U. S. Patent No. 887,357 (May 12, 1908); Canadian Patent No. 114,737 (Oct. 20, 1908).

[15] The tendency to *radiate* increases as the square of the frequency.

[16] Nor the case of high powered VLF stations used for communication with submarines, such as the Navy station at Cutler, Maine, which operates on 14.7 kHz. In this instance more than a megawatt of power is radiating from the antenna system.

[17] Charles Süsskind, "Observations of Electromagnetic Wave Radiation before Hertz," *ISIS 55* (March, 1964), 32-42.

[18] *Ibid*, 37-39.

[19] *Marconi Wireless Telegraph Co. of America vs. DeForest Wireless Telegraph Co.* United States Circuit Court for the Southern District of New York. In Equity No. 8211 (1904).

[20] We are indebted to J. Brittain of the Georgia Institute of Technology for calling our attention to the early Stone experiments. See Clark Collection SRM 4-1230, John Stone Stone, Report (1892) Mechanical Department of American Bell Telephone Co. Also commentary in letter of Dec. 22, 1944 from Lloyd Espenschied to G. H. Clark, CWC 4-2839A. A published source is George H. Clark, *The Life of John Stone Stone.* (San Diego: Frye and Smith Ltd., 1946) 35-37.

[21] Helen Fessenden, *Fessenden: Builder of Tomorrows.* (New York: Coward-McCann, 1940), Chapter XV. See also, R. A. Fessenden, "Wireless Telephony," *Transactions of the American Institute of Electrical Engineers, 1908.* Clark Collection CWC 135-178A.

[22] The distortion level, while less than that of the spark radiotelephone, was worse than that of the alternator.

[23] John Grant, "Experiments and Results in Wireless Telephony," *The American Telephone Journal,* (January 26 and February 2, 1907).

[24] Letter of January 29, 1932, Reginald A. Fessenden to S. M. Kintner, Vice-President, Westinghouse Electric & Mfg. Co. Clark Collection CWC 135-246A.

[25] Call Letters and Log Book of Francis Arthur Hart, 1906-1909. Smithsonian Institution Cat. No. 329,734. Hart also reports the DeForest arc experiments of March 20, May 7 and May 9, 1907.

[26] Lee DeForest, *Father of Radio.* (Chicago: Wilcox-Follett, 1950), 221.

[27] H. J. Meneratti was wireless operator aboard the Ohio. The basic research material for this section is based upon his notes in the Div. of Electricity & Nuclear Energy files of the Smithsonian. See also data in Clark Collection Class 134 History of Broadcasting and Class 135 History of Radiotelephony. A good published source is L. S. Howeth, *History of Communications-Electronics in the United States Navy.* (Washington: Government Printing Office, 1963), 169-172.

[28] DeForest, *Op. Cit.,* 225; Georgette Carneal, *A Conqueror of Space.* (New York: Horace Liveright, 1930), 205-209.

[29] R. A. Heising, *Montauk-Arlington Radio Telephone Tests of 1915* (1938), Clark Collection CWC 135-085A. A brief account of the tests is contained in: William Peck Banning, *Commercial Broadcasting Pioneer.* (Cambridge: Harvard University Press, 1946), 6-7.

[30] DeForest, *Op. Cit.,* 338.

[31] U. S. Department of Commerce, *Commercial and Government Radio Stations of the United States* (1920).

[32] A full account of Elwell's role in radio engineering may be found in: *Pioneer Work in Radio Telephony and Telegraphy* by Cyril Elwell. (Smithsonian Institution: Clark Collection CWC 135-245A). A popularized though extensive account of West Coast developments may be found in Jane Morgan, *Electronics in the West: The First Fifty Years.* (Palo Alto: National Press Books, 1967).

[33] Herrold's role will be fully discussed in Joseph E. Baudino's future article, which will consider individual station histories. See also Gordon B. Greb, "The Golden Anniversary of Broadcasting," JOURNAL OF BROADCASTING, III:1 (Winter, 1958-59), 3-13.

[34] U. S. Department of Commerce, *Radio Stations of the United States.* (1914 and 1915 editions).

[35] Eugene Lyons, *David Sarnoff: A Biography.* (New York: Harper & Row, 1966), 70-73; David Sarnoff, *Looking Ahead.* (New York: McGraw Hill, 1968), 31-34; Gleason Archer, *History of Radio to 1926.* (New York: American Historical Society, 1938) 110-113.

[36] The complexities of the patent problem are told in W. Rupert MacLaurin, *Invention and Innovation in the Radio Industry.* (New York: Macmillan Co., 1949).

[37] Letter of Jan. 31, 1922 from David Sarnoff to C. D. Young of RCA restates the "Radio Music Box" proposal, and discusses its previous introduction in 1915 as well as another memorandum of Jan. 31, 1920. Sarnoff does mention the lack of a suitable radiotelephone transmitter and compact receiver in the earlier period, inferring that this retarded the introduction of broadcasting. It might be argued, however, that had the industry responded with some inspiration to his initial proposal, some of the difficulties vis-a-vis the patent situation could have been resolved. In point of fact, the equipment needed for broadcasting was close to practical realization. The Bell System's radiotelephone tests of 1915 included oscillator, modulator and power amplifier tubes. DeForest's "oscillion" transmitting triodes were also available that year. Receivers such as the DeForest RJ-4 and RJ-5 audion detectors, with necessary receiving transformers were available in 1914 at prices in the $26-40 category. These would fulfill the "Music Box" criterion, albeit with lack of sensitivity compared to later circuitry. As fate would have it, however, World War I provided the training ground for many of the first radiotelephone applications and for mass production of vacuum tubes, since manufacturers agreed to suspend any patent litigation for the duration of the war.

Note on sources: The Clark Collection of manuscripts and photographs is located at the Smithsonian Institution's Division of Electricity and Nuclear Energy. One of the most extensive collections of documents pertaining to the history of radio technology, it was compiled by George H. Clark (1881-1956), who was RCA's historian for more than 30 years. The Collection was used extensively by L. S. Howeth in his work (cited in footnote 27).

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HERTZ'S RESEARCHES ON ELECTRICAL OSCILLATIONS

C. W. de Tunzelmann

HERTZ'S RESEARCHES ON ELECTRICAL OSCILLATIONS.*

BY G. W. DE TUNZELMANN, B. SC.

H. Hertz has been engaged for some time past in a series of researches on electrical oscillations, which have led to results of very exceptional importance, and as these results throw considerable light on the nature of electrical action, it will be of interest to have a connected account of the investigations, to which I therefore propose to devote a short series of papers.

In Hertz's first paper on the subject, viz, "On Very Rapid Electrical Oscillations" (Wiedemann's *Annalen*, 1887, vol. XXXI, page 421), he refers to a paper by Colley, "On Some New Methods for Observing Electrical Oscillations, with Applications" (*ibid.*, vol. XXVI, page 432), who calls attention to the fact that Sir William Thompson in 1853, showed the possibility of producing electrical oscillations by the discharge of a charged conductor, and gives references to all the investigations in the same direction which were known to him.†

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* From *The Electrician* (published in London), Sept. 14 to Nov. 16, 1888, vol. XXI, pp. 587, 625, 663, 696, 725, 757, 788; vol. XXII, pp. 16, 41.

† For the benefit of readers who may wish to pursue the subject further the list is reproduced below:—

[Joseph Henry was the first to experimentally demonstrate the oscillation of electrical discharges, in June, 1842. *Proceedings American Philosoph. Soc.*, vol. II, pages 193-196. Also, "Scientific Writings of Joseph Henry," published by the Smithsonian Institution; vol. I, page 200.]

Von Helmholtz, "Erhaltung der Kraft." Berlin, 1847: Translated and published in Tyndall's "Scientific Memoirs," London, 1853, vol. I, page 143. Also, "Gesammelte Abhandlungen," vol. I, page 531.

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Feddersen, Poggendorff's *Annalen*, 1858, vol. CIII, page 69; 1859, vol. CVIII, page 497; 1861, vol. CXII, page 452; 1861, vol. CXIII, page 437; 1862, vol. CXV, page 336; 1862, vol. CXVI, page 132.

Kirchhoff, "Gesammelte Abhandlungen," page 168, containing remarks on and corrections of some of Feddersen's results.

Von Oettingen, Poggendorff's *Annalen*, 1862, vol. CXV, page 513; and Jubelband of same, 1874, page 269.

Bernstein, Poggendorff's *Annalen*, 1871, vol. CXLII, pages 54-88.

Schiller, Poggendorff's *Annalen*, 1872, vol. CLII, page 535.

Mouton, Thèse, Paris, 1876. *Journal des Physique*, 1876, vol. VI, pages 5 and 46.

According to these investigations, the electrical oscillations produced in an open circuit by means of an induction coil are measured by ten thousandths of a second, while in the case of the oscillatory discharge of a Leyden jar they are about a hundred times as rapid, as was shown by Feddersen.

According to theory, still more rapid oscillations should be possible in an open circuit of wire of good conducting material, provided its ends are not connected with conductors of any considerable capacity; but it is not possible to determine from theory whether measurable oscillations are actually produced. Some observations of Hertz's led him to believe that under certain circumstances oscillations of this kind were produced, and his researches show that this is so, and that the oscillations are about a hundred times as rapid as those observed by Feddersen; so that their periods are measured by hundred millionths of a second, and they therefore occupy a position intermediate between acoustic and luminous vibrations.

Preliminary Experiments.—It is known that if in the secondary circuit of an induction coil there be inserted, in addition to the ordinary air space, across which sparks pass, a Riess spark micrometer, with its poles joined by a long wire, the discharge will pass across the air space of the micrometer in preference to following the path of least resistance through the wire, provided this air space does not exceed a certain limit, and it is upon this principle that lightning protectors for telegraph lines are constructed. It might be expected that the sparks could be made to disappear by diminishing the length and resistance of the connecting wire; but Hertz finds that though the length of the sparks can be diminished in this way, it is almost impossible to get rid of them entirely, and they can still be observed when the balls of the micrometer are connected by a thick copper wire only a few centimeters in length.

This shows that there must be variations in the potential measureable in hundredths of a volt in a portion of the circuit only a few centimeters in length, and it also gives an indirect proof of the enormous rapidity of the discharge, for the difference of potential between the micrometer knobs can only be due to self-induction in the connecting wire. Now the time occupied by variations in the potential of one of the knobs must be of the same order as that in which these variations can be transmitted through a short length of a good conductor to the second knob. The resistance of the wire connecting the knobs is found to be without sensible effect on the results.

L. Lorenz, Wiedemann's *Annalen*, 1879, vol. VII, page 161.

Olearsky, Verhandlungen der Academie von Krakau, 1882, vol. VII, page 141.

Kolacek, Beiblätter zu Wiedemann's *Annalen*, 1883, vol. VII, page 541 (abstract of a paper published in the reports of the Bohemian Scientific Society in 1882).

Bichat et Blondlot, *Comptes Rendus*, 1882, vol. XCIV, page 1590.

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In Fig. 1, *A* is an induction coil and *B* a discharge. The wire connecting the knobs 1 and 2 of the spark micrometer *M*, consists of a rectangle, half a meter in length, of copper wire 2 millimeters in diameter. This rectangle is connected with the secondary circuit of the coil in the manner shown in the diagram; and when the coil is in action, sparks—sometimes several millimeters in length—are seen to pass between the knobs 1 and 2, showing that there are violent electrical oscillations, not only in the secondary circuit itself, but in any conductor in contact with it. This experiment shows even more clearly than the previous one that the rapidity of the oscillations is comparable with the velocity of transmission of electrical disturbances through the copper wire, which, according to all the evidence at our disposal, is nearly equal to the velocity of light.

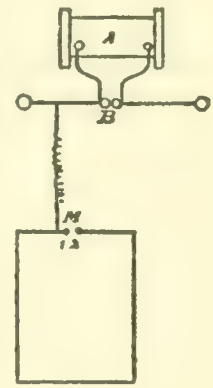

FIG. 1.

In order to obtain micrometer sparks some millimeters in length, a powerful induction coil is required, and the one used by Hertz was 52 centimeters in length and 20 centimeters in diameter, provided with a mercury contact breaker, and excited by six large Bunsen cells. The discharger terminals consisted of brass knobs 3 centimeters in diameter. The experiments showed that the phenomenon depends to a very great extent on the nature of the sparks at the discharger, the micrometer sparks being found to be much weaker when the discharge in the secondary circuit took place between two points, or between a point and a plate, than when knobs were used. The micrometer sparks were also found to be greatly enfeebled when the secondary discharge took place in a rarified gas, and also when the sparks in the secondary were less than half a centimeter in length, while on the other hand, if they exceeded 1½ centimeters the sparks could no longer be observed between the micrometer knobs. The length of secondary spark which was found to give the best results, and which was therefore employed in the further observations, was about three-quarters of a centimeter.

Very slight differences in the nature of the secondary sparks were found to have great effect on those at the micrometer, and Hertz states that after some practice he was able to determine at once from the sound and appearance of the secondary spark whether it was of a kind to give the most powerful effects at the micrometer. The sparks which gave the best results were of a brilliant white color, only slightly jagged, and accompanied by a sharp crack.

The influence of the spark is readily shown by increasing the distance between the discharger knobs beyond the striking distance, when the micrometer sparks disappear entirely, although the variations of potential are now greater than before. The length of the micrometer circuit has naturally an important influence on the length of the spark, as

the greater its length the greater will be the retardation of the electrical wave in its passage through it from one knob of the micrometer to the other.

The material, the resistance, and the diameter, of the wire of which the micrometer circuit is formed, have very little influence on the spark. The potential variations can not therefore be due to the resistance, and this was to be expected, for the rate of propagation of an electrical disturbance along a conductor depends mainly on its capacity and co-efficient of self-induction, and only to a very small extent on its resistance. The length of the wire connecting the micrometer circuit with the secondary circuit of the coil is also found to have very little influence, provided it does not exceed a few meters in length. The electrical disturbances must therefore traverse it without undergoing any appreciable change. The position of the point of the micrometer circuit which is joined to the secondary circuit, is on the other hand of the greatest importance, as would be expected, for if the point is placed symmetrically with respect to the two micrometer knobs the variations of potential will reach the latter in the same phase, and there will be no effect, as is verified by observation. If the two branches ot the micrometer circuit on each side of the point of contact of the connection with the secondary are not symmetrical, the spark can not be made to disappear entirely; but a minimum effect is obtained when the point of contact is about half-way between the micrometer knobs. This point may be called the null point.

Fig. 2 shows the arrangement employed, *e* being the null point of the rectangular circuit, which is 125 centimeters long by 80 centimeters broad. When the point of contact is at *a* or *b*, sparks of from 3 to 4 millimeters in length are observed, when it is at *e* no sparks are seen, but they can be made to re-appear by shifting the point of contact a few centimeters to the right or left of the null point. It should be noted that sparks only a few hundredths of a millimeter in length can be observed. If when the point of contact is at *e* another conductor is placed in contact with one of the micrometer knobs the sparks re-appear.

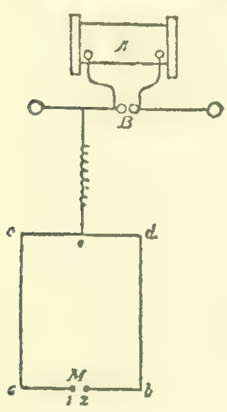

Fig. 2.

Now the addition of this conductor can not produce any alteration in the time taken by the disturbances proceeding from *e* to reach the knobs, and therefore the phenomenon can not be due simply to single waves in the directions *c a* and *d b* respectively, but must be due to repeated reflection of the waves until a condition of stationary vibration is attained, and the addition of the conductor to one of the knobs must diminish or prevent the reflection of the waves from that terminal. It must be assumed then, that definite oscillations are set up in the micrometer cir-

cuit just as an elastic bar is thrown into definite vibrations by blows from a hammer. If this assumtion is correct, the condition for the disappearance of the sparks at M will be that the vibration periods of the two branches $c\,1$ and $c\,2$ shall be equal. These periods are determined by the products of the coefficients of self-induction of these conductors into the capacity of their terminals, and are practically independent of their resistances.

In confirmation of this, it is found that if when the point of contact is at e and the sparks have been made to re-appear by connecting a conductor with one of the knobs, this conductor is replaced by one of greater capacity, sparking is greatly increased. If a conductor of equal capacity is connected with the other micrometer knob the sparks disappear again; the effect of the first conductor can also be counteracted by shifting the point of contact towards it, thereby diminishing the self-induction in that branch. The conclusions were further confirmed by the results obtained when coils of copper wire were inserted into one or other and then into both of the branches of the micrometer circuit.

Hertz supposed that as the self-induction of iron wires is, for slow alternations, from eight to ten times that of copper wires, therefore a short iron wire would balance a long copper one; but this was not found to be the case, and he concludes that, owing to the great rapidity of the alternations, the magnetism of the iron is unable to follow them and therefore has no effect on the self-induction.*

Induction phenomena in open circuits.—In order to test more fully his conclusion that the sparks obtained in the experiments described in the previous section, were due to self-induction, Dr. Hertz placed a rectangle of copper wire with sides 10 and 20 centimeters in length, respectively, broken by a short air space, with one of its sides parallel and close to various portions of the secondary circuit of the coil, and of the micrometer circuit, with solid di-electrics interposed, to obviate the possibility of sparking across, and he found that sparking in this rectangle invariably accompanied the discharges of the induction coil, the longest sparks being obtained when a side of the rectangle was close to the discharger.

A copper wire, $i\ g\ h$ (Fig. 3), was next attached to the discharger, and a side of the micrometer circuit, which was supported on an insulating stand, was placed parallel to a portion of this wire, as shown in the diagram. The sparks at M were then found to be extremely feeble

* In a note in Wiedemann's *Annalen*, vol. XXXI, page 543, Dr. Hertz statest hat since the publication of his paper in the same volume, he had found that Von Bezold had published a paper in 1870 (Poggendorff's *Annalen*, vol. CXL, page 541), in which he had arrived by a different method of experimenting at similar results and conclusions as those given by him under the head of Preliminary Experiments.

until a conductor, C, was attached to the free end, h, of the copper wire, when they increased to 1 or 2 millimeters in length. That the action of C was not an electrostatic one was shown by its producing no effect when attached at g instead of at h. When the knobs of the discharger B were so far separated that no sparking took place there, the sparks at M were also found to disappear, showing that these were due to the sudden discharges and not to the charging current. The sparks at the discharger which produced the most effect at the micrometer were of the same character as those described in my last paper. Sparks were also found to occur between the micrometer circuit and insulated conductors in its vicinity. The sparks became much shorter when conductors of larger capacity were attached to the micrometer knobs, or when these were touched by the hand, showing that the quantity of electricity in motion was too small to charge these conductors to a similarly high potential. Joining the micrometer knobs by a wet thread did not perceptibly diminish the strength of the sparks. The effects in the micrometer circuit were not of sufficient strength to produce any sensation when it was touched or the circuit completed through the body.

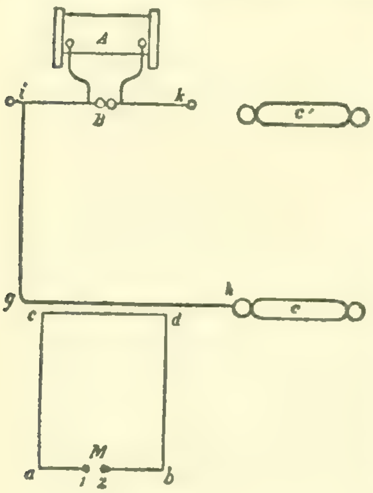

Fig. 3.

In order to obtain further confirmation of the oscillatory nature of the current in the circuit $k\,i\,h\,g$ (Fig. 3), the conductor C was again attached to h, and the micrometer knobs drawn apart until sparks only passed singly. A second conductor, C', as nearly as possible similar to C, was then attached to k, when a stream of sparks was immediately observed, and it continued when the knobs were drawn still further apart. This effect could not be ascribed to a direct action of the portion of circuit $i\,k$, for in this case the action of the portion of circuit $g\,h$ would be weakened, and it must therefore have consisted in C' acting on the discharging current of C, a result which would be quite incomprehensible unless the current in $g\,h$ were of an oscillatory character.

Since an oscillatory motion between C and C' is essential for the production of powerful inductive effects, it will not be sufficient for the spark to occur in an exceedingly short time, but the resistance must at the same time not exceed certain limits. The inductive effects will therefore be excessively small if the induction coil included in the circuit $C\,C'$ is replaced by an electrical machine alternately charging and discharging itself, or if too small an induction coil is used; or again if the air space between the discharger knobs is too great, as in all these cases the motion ceases to be oscillatory.

The reason that the discharges of a powerful induction coil gives rise to oscillatory motion is that firstly, it charges the terminals C and C' to a high potential; secondly, it produces a sudden spark in the intervening circuit; and thirdly, as soon as the discharge begins the resistance of the air space is so much reduced as to allow of oscillatory motion being set up. If the terminal conductors are of very large capacity, for example, if the terminals are in connection with a battery, the current of discharge may indefinitely reduce the resistance of the air space, but when the terminal conductors are of small capacity this must be done by a separate discharge, and therefore under the conditions of the author's experiments, an induction coil was absolutely essential for the production of the oscillations.

As the induced sparks in the experiment last described were several millimeters in length, the author modified it by using the arrangement shown in Fig. 4, and greatly increasing the distance between the micrometer circuit and the secondary circuit of the induction coil. The terminal conductors C and C' were 3 meters apart, and the wire between them was of copper, 2 millimeters in diameter, with the discharger B at its center.

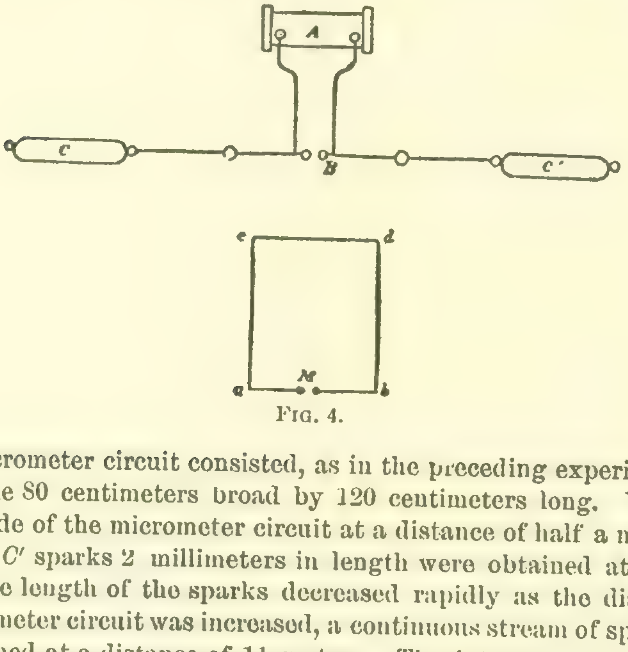

FIG. 4.

The micrometer circuit consisted, as in the preceding experiments, of a rectangle 80 centimeters broad by 120 centimeters long. With the nearest side of the micrometer circuit at a distance of half a millimeter from $C\ B\ C'$ sparks 2 millimeters in length were obtained at M, and, though the length of the sparks decreased rapidly as the distance of the micrometer circuit was increased, a continuous stream of sparks was still obtained at a distance of $1\frac{1}{2}$ meters. The intervention of the observer's body between the micrometer circuit and the wire $C\ B\ C'$ produced no visible effect on the stream of sparks at M. That the effect was really due to the rectilinear conductor $C\ B\ C'$ was proved by the fact that when one or other, or both, halves of this conductor were removed the sparks at M ceased. The same effect was produced by draw-

ing the knobs of the discharger B apart until sparks ceased to pass showing that the effect was not due to the electro-static potential difference of C C', as this would be increased by separating the discharger knobs beyond sparking distance.

The closed micrometer circuit was then replaced by a straight copper wire, slightly shorter than the distance C C', placed parallel to C B C', and at a distance of 60 centimeters from it. This wire terminated in knobs, 10 centimeters in diameter, attached to insulating supports, and the spark micrometer divided it into two equal parts. Under these circumstances sparks were obtained at the micrometer as before.

With the rectilinear open micrometer circuit sparks were still observed at the micrometer when the discharger knobs of the secondary coil circuit were separated beyond sparking distance. This was of course due simply to electro-static induction, and shows that the oscillatory current in C C' was superposed upon the ordinary discharges. The electro-static action could be got rid of by joining the micrometer knobs by means of a damp thread. The conductivity of this thread was therefore sufficient to afford a passage to the comparatively slow alternations of the coil discharge, but was not sufficient to provide a passage for the immeasureably more rapid alternations of the oscillatory current. Considerable sparking took place at the micrometer when its distance from C B C' was 1 or 2 meters, and faint sparks were distinguishable up to 3 meters. At these distances it was not necessary to use the damp thread to get rid of the electro-static action, as owing to its diminishing more rapidly with increase of distance than the effect of the current induction, it was no longer able to produce sparks in the micrometer, as was proved by separating the discharger knobs beyond speaking distance, when sparks could no longer be perceived at the micrometer.

Resonance phenomena.—In order to determine whether, as some minor phenomena had led the author to suppose, the oscillations were of the nature of a regular vibration, he availed himself of the principle of resonance. According to this principle, an oscillatory current of definite period would, other conditions being the same, exert a much greater inductive effect upon one of equal period than upon one differing even slightly from it.*

If then two circuits are taken, having as nearly as possible equal vibration periods, the effect of one upon the other will be diminished by altering either the capacity or the co-efficient of self-induction of one of them, as a change in either of them would alter the period of vibration of the circuit.

This was carried out by means of an arrangement very similar to that of Fig. 4. The conductor C C' was replaced by a straight copper wire 2.6 meters in length and 5 millimeters in diameter, divided into two equal parts, as before, by a discharger. The discharger knobs were attached

* See Oberbeck, Wiedemann's *Annalen*, 1885, vol. XXVI, p. 245.

directly to the secondary terminals of the induction coil. Two hollow zinc spheres, 30 centimeters in diameter, were made to slide on the wire, one on each side of the discharger, and since, electrically speaking, these formed the terminals of the conductor, its length could be varied by altering their position. The micrometer circuit was chosen of such dimensions as to have, if the author's hypothesis were correct, a slightly shorter vibration period than that of $C\ C'$. It was formed of a square, with sides 75 centimeters in length, of copper wire 2 millimeters in diameter, and it was placed with its nearest side parallel to $C\ B\ C'$, and at a distance of 30 centimeters from it. The sparking distance at the micrometer was then found to be 0.9 millimeter. When the terminals of the micrometer circuit were placed in contact with two metal spheres, 8 centimeters in diameter, supported on insulating stands, the sparking distance could be increased up to 2.5 millimeters. When these were replaced by much larger spheres the sparking distance was diminished to a small fraction of a millimeter. Similar results were obtained on connecting the micrometer terminals with the plates of a Kohlrausch condenser. When the plates were far apart the increase of capacity increased the sparking distance, but when the plates were brought close together the sparking distances again fell to a very small value.

The simplest method of adjusting the capacity of the micrometer circuit is to suspend to its ends two parallel wires, the distance and lengths of which are capable of variation. By this means the author succeeded in increasing the sparking distance up to 3 millimeters, after which it diminished when the wires were either lengthened or shortened. The decrease of the sparking distance on increasing the capacity was naturally to be expected; but it would be difficult to understand, except on the principle of resonance, why a decrease of the capacity should have the same effect.

The experiments were then varied by diminishing the capacity of the circuit $C\ B\ C'$ so as to shorten its period of oscillation, and the results confirmed those previously obtained, and a series of experiments in which the lengths and capacities of the circuits were varied in different ways showed conclusively that the maximum effect does not depend on the conditions of either one of the two circuits, but on the existence of the proper relation between them.

When the two circuits were brought very close together, and the discharger knobs separated by an interval of 7 millimeters, sparks were obtained at the micrometer, which were also 7 millimeters in length, when the two circuits had been carefully adjusted to have the same period. The induced *electro-motive forces* must in this case have attained nearly as high a value as the inducing ones.

To show the effect of varying the co-efficient of self-induction, a series of rectangles $a\ b\ c\ d$ (Fig. 4), were taken, having a constant breadth $a\ b$, but a length $a\ c$ continually increasing from 10 centimeters up to 250 centimeters; it was found that the maximum effect was obtained

with a length of 1.8 meters. The quantitative results of these experiments are shown in Fig. 5, in which the abscissæ of the curve are the double lengths of the rectangles, and the ordinates represent the corresponding maximum sparking distances. The sparking distances could not be determined with great exactness, but the errors were not sufficient to mask the general nature of the result.

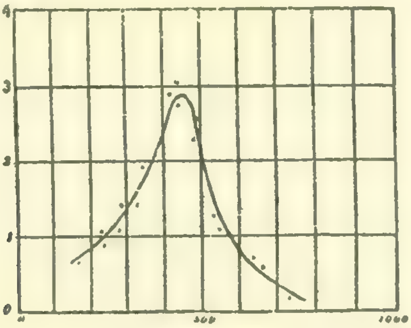

FIG. 5.

Curve showing relation between length of side of rectangle (taken as abscissa) and maximum sparking distance (taken as ordinate), the sides consisting of straight wires of varying lengths,

In a second series of experiments the sides *a c* and *b d* were formed of loose coils of wire which were gradually pulled out, and the result is shown in Fig. 6. It will be seen that the maximum sparking distance was attained for a somewhat greater length of side, which is explained by the fact that in the latter experiments the self-induction only was increased by increase of length, while in the former series the capacity was increased as well. Varying the resistance of the micrometer circuit by using copper and German silver wires of various diameters was found to have no effect on the period of oscillation, and extremely little on the sparking distance.

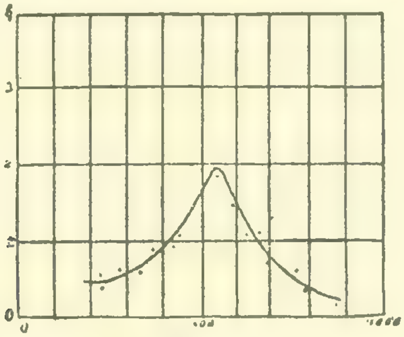

FIG. 6.

Curve showing relation between length of side of rectangle (taken as abscissa) and maximum sparking distance (taken as ordinate), the sides consisting of spirals gradually drawn out.

When the wire $c d$ was surrounded by an iron tube, or when it was replaced by an iron wire, no perceptible effect was obtained, confirming the conclusion previously arrived at that the magnetism of the iron is unable to follow such rapid oscillations, and therefore exerts no appreciable effect.

Nodes.—The vibrations in the micrometer circuit which have been considered are the simplest ones possible, but not the only ones. While the potential at the ends alternates between two fixed limits, that at the central portion of the circuit retains a constant mean value. The electrical vibration therefore has a node at the center, and this will be the only nodal point. Its existence may be proved by placing a small insulated sphere close to various portions of the micrometer circuit while sparks are passing at the discharger of the coil, when it will be found that if the sphere is placed close to the center of the circuit the sparking will be very slight, increasing as the sphere is moved farther away. The sparking cannot however be entirely got rid of, and there is a better way of determining the existence and position of the node. After adjusting the two circuits to unison, and drawing the micrometer terminals so far apart that sparks can only be made to pass by means of resonant action, let different parts of the circuit be touched by a conductor of some capacity, when it will be found that the sparks disappear, owing to interference with the resonant action, except when the point of contact is at the center of the circuit. The author then endeavored to produce a vibration with two nodes, and for this purpose

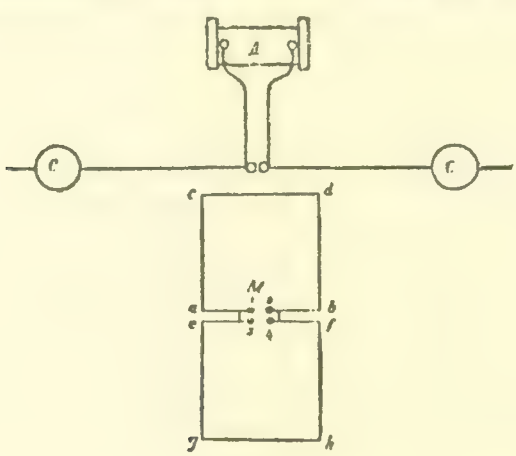

FIG. 7.

he modified the apparatus previously used by adding to the micrometer circuit a second rectangle $e f g h$ exactly similar to the first (as shown in Fig. 7), and joining the points of the circuit near the terminals by wires 13 and 24, as shown in the diagram.

The whole system then formed a closed metallic circuit, the fundamental vibration of which would have two nodes. Since the period of this vibration would necessarily agree closely with that of each half of the circuit, and therefore with that of the circuit $C\ C'$, it was to be expected that the vibration would have a pair of loops at the junctions 1 and 3, and 2 and 4, and a pair of nodes at the middle points of *c d* and *g h*. The vibrations were determined by measuring the sparking distance between the micrometer terminals 1 and 2. It was found that—contrary to what was expected—the addition of the second rectangle diminished this sparking distance from about 3 millimeters to about 1 millimeter. The existence of resonant action between the circuit $C\ C'$ and the micrometer circuit was however fully demonstrated, for any alteration in the circuit *e f g h*, whether it consisted in increasing or in decreasing its length, diminished the sparking distance. It was also found that much weaker sparking took place between *c d* or *g h* and an insulated sphere, than between *a e* or *b f* and the same sphere, showing that the nodes were in *c d* and *g h*, as expected. Further, when the sphere was made to touch *c d* or *g h* it had no effect on the sparking distance of 1 and 2; but when the point of contact was at any other portion of the circuit the sparking distance was diminished, showing that these nodes did really belong to the vibration, the resonant action of which increased this sparking distance.

The wire joining the points 2 and 4 was then removed. As the strength of the induced oscillatory current should be zero at these points, the removal ought not to disturb the vibrations, and this was shown experimentally to be the case, the resonant effects and the position of the nodes remaining unchanged. The vibration with two nodal points was of course not the fundamental vibration of the circuit, which consisted of a vibration with a node between *a* and *e*, and for which the highest values of the potential were at the points 2 and 4.

When the spheres forming the terminals at these points were brought close together, slight sparking was found to take place between them, which was attributed to the excitation, though only to a small extent, of the fundamental vibration. This explanation was confirmed in the following manner: The sparks between 1 and 2 were broken off, leaving only the sparks between 2 and 4, which measured the intensity of the fundamental vibration. The period of vibration of the circuit $C\ C'$ was then increased by drawing it out to its full length, and thereby increasing its capacity, when it was observed that the sparking gradually increased to a maximum, and then began to diminish again. The maximum value must evidently occur when the period of vibration of the circuit $C\ C'$ is the same as that of the fundamental vibration of the micrometer circuit, and it was shown that when the sparking distance between 2 and 4 had its maximum value, the sparks corresponded to a vibration with only one nodal point, for the sparks ceased when the previously existing nodes were touched by a conductor, and the only point

where contact could take place without effect on the sparking was between a and c. These results show that it is possible to excite at will in the same conductor either the fundamental vibration or its first overtone, to use the language of acoustics.

Hertz appears to consider it very doubtful whether it will be possible to get higher overtones of electrical vibration, the difficulty of obtaining such lying not only in the method of observation, but also in the nature of the oscillations themselves. The intensity of these is found to vary considerably during a series of discharges from the coil even when all the circumstances are maintained as constant as possible, and the comparative feebleness of the resonant effects shows that there must be a considerable amount of damping. There are moreover many secondary phenomena which seem to indicate that irregular vibrations are superposed upon the regular ones, as would be expected in complex systems of conductors. If therefore we wish to compare electrical oscillations (from a mathematical point of view) with those of acoustics, we must seek our analogy in the high notes intermixed with irregular vibrations, obtained, say, by striking a wooden rod with a hammer, rather than in the comparatively slow harmonic vibration of tuning-forks or strings; and in the case of vibrations of the former class we have to be contented, even in the study of acoustics, with little more than indications of such phenomena as resonance and nodal points.

Referring to the conditions to be fulfilled in order to obtain the best results, should other physicists desire to repeat the experiments, Dr. Hertz notes a fact of very considerable interest and novelty, namely, that the spark from the discharger should always be visible from the micrometer, as when this was not the case, though the phenomena observed were of the same character, the sparking distance was invaribly diminished.

Theory of the experiments.—The theories of electrical oscillations which have been developed by Sir William Thomson, von Helmholtz, and Kirchhoff, have been shown* to hold good for the open-circuit oscillations of induction apparatus, as well as for the oscillatory Leyden-jar discharge; and although Dr. Hertz has not succeeded in obtaining definite quantitative results to compare with theory, it is of interest to inquire whether the observed results are of the same order as those indicated by theory.

Hertz considers, in the first place, the vibration period. Let T be the period of a single or half vibration proper to the conductor exciting the micrometer circuit; P its co-efficient of self-induction in absolute electro-magnetic measure expressed therefore in centimeters; C the capacity of one of its terminals in electro-static measure, and therefore also expressed in centimeters; and v the velocity of light in centimeter-seconds.

* Lorentz, Wiedemann's *Annalen*, 1879, vol. VII, p. 161.

Then, if the resistance of the conductor is small,

$$T=\frac{\pi\sqrt{PC}}{v}$$

In the case of the resonance experiments, the capacity C was approximately the radius of the sphere forming the terminal, so that $C=15$ centimeters. The co-efficient of self-induction was that of a wire of length $l=150$ centimeters, and diameter $d=\frac{1}{2}$ centimeter.

According to Neumann's formula,

$$P=\int\int\frac{\cos\varepsilon}{r}d\,s\,d\,s',$$

which gives in the case considered

$$P=2\,l\left(\log\frac{4\,l}{d}-0.75\right)=1902^{cm}.$$

As however it is not quite certain that Neumann's formula is applicable to an open circuit, it is better to use von Helmholtz's more general formula, containing an undetermined constant k, according to which

$$P=2\,l\left(\log\frac{4\,l}{d}-0.75+\frac{1-k}{2}\right).$$

Putting $k=1$ this reduces to Neumann's formula; for $k=0$ it reduces to that of Maxwell; and for $k=-1$ to Weber's. The greatest difference in the values of P obtained by giving these different values to k would not exceed a sixth of its mean value, and therefore for the purposes of the present approximation it is enough to assume that k is not a large positive or negative number; for if the number 1902 does not give the correct value of the co-efficient for the wire 150 cm. in length, it will give the value corresponding to a conductor not differing greatly from it in length.

Taking $P=1902^{cm}$., we have $\pi\sqrt{CP}=531^{cm}$., which represents the distance traversed by light during the oscillation, or, according to Maxwell's theory, the length of an electro-magnetic æther wave. The value of T is then found to be ($\frac{1.77}{100,000,000}$) 1.77 hundred millionths of a second, which is of the same order as the observed results.

The ratio of damping is then considered. In order that oscillations may be possible the resistance of the open circuit must be less than $2v\sqrt{\frac{P}{C}}$. For the exciting circuit used this gives 676 ohms as the upper limit of resistance. If the actual resistance r is sensibly below this limit, the ratio of damping will be $e^{\frac{rT}{2P}}$. The amplitude will therefore be reduced in the ratio 1:2.71 in

$$\frac{2\,P}{r\,T}=\frac{2\,v}{\pi r}\sqrt{\frac{P}{C}}=\frac{676}{\pi r}=\frac{215}{r}$$

oscillations. Unfortunately we have no means of determining the resistance of the air space traversed by the spark, but as the resistance

of a strong electric arc is never less than a few ohms we shall be justified in assuming this as the minimum limit. From this it would follow that the number of oscillations due to a single impulse must be reckoned in tens, and not in hundreds or thousands, which is in accordance with the character of the experimental results, and agrees with the results observed in the case of the oscillatory Leyden-jar discharge. In the case of closed metallic circuits, on the other hand, theory indicates that the number of oscillations before equilibrium is attained must be reckoned by thousands.

Hertz compares lastly the order of the inductive actions of these oscillations, according to theory, with that of the effects actually observed. To do this it must be noted that the maximum *electro-motive force* induced by the oscillation in its own circuit is approximately equal to the maximum potential difference at its extremities; for if there were no damping, these quanities would be identical, since at any moment the potential difference at the extremities and the E. M. F. of induction would be in equilibrium. In the experiments under consideration the potential difference at the extremities was such as to give a spark 7 to 8^{mm}. in length, which must therefore represent the maximum inductive action excited in its own circuit by the oscillation. Again, at any instant the induced E. M. F. in the micrometer circuit must be to that in the exciting conductor in the same ratio as that of the co-efficient of mutual induction p of the two circuits to the co-efficient of self-induction P of the exciting circuit. The value of p for the case considered is easily calculated from the ordinary formulæ, and it is found to lie between one-ninth and one-twelfth of P. This would only give sparks of from $\frac{1}{2}$ to $\frac{2}{3}^{mm}$. in length, so that according to theory visible sparks ought in any case to be obtained; but, on the other hand, sparks several millimeters in length, as were obtained in the experiments previously described, can only be explained on the assumption that the successive inductive actions produce an accumulative effect; so that theory indicates the necessity of the existence of the resonant effects actually observed.

Dr. Hertz was at first inclined to suppose that as the micrometer circuit was only broken by the extremely short air space limited by the maximum sparking distance under the conditions of the experiment, it might therefore be treated as a closed circuit, and only the total induction considered. The ordinary methods of electro-dynamics give the means of completely determining the total inductive effect of a current element on a closed circuit, and would therefore in this case have sufficed for the investigation of the phenomena observed. He found however that the treatment of the micrometer circuit as a closed circuit led to incorrect results, so that it, as well as the primary, had to be treated as an open circuit, and therefore a knowledge of the total induc-

tion was insufficient, and it became necessary to consider the value both of the E. M. F. induction and of the electro-static E. M. F. due to the charged extremeties of the exciting circuit at each point of the micrometer circuit.

The investigations to which these considerations led are described by Dr. Hertz in a paper "On the Action of a Rectilinear Electrical Oscillation upon a Circuit in its Vicinity," published in Wiedemann's *Annalen*, 1888, vol. XXXIV, page 155.

In what follows, the exciting circuit will be spoken of as the primary, and the micrometer circuit as the secondary. Hertz points out that the reason that the electro-static effect can not be neglected is to be found in the extreme rapidity with which the electro-static forces change their sign. If the electro-static alternations in the primary were comparatively slow they might attain a very high intensity without giving rise to a spark in the secondary, since the electro-static distribution on the secondary would vary so as to remain in equilibrium with the external E. M. F. This however is impossible, because the variations in direction follow each other too rapidly for the distribution to follow them.

In the present investigations the primary circuit consisted of a straight copper wire 5 millimeters in diameter, carrying at its extremeties hollow zinc spheres 30 centimeters in diameter. The centers of the spheres were 1 meter apart, and at the middle of the wire was an air space three-fourths centimeter in length. The wire was placed in a horizontal position, and the observations were all made at points near to the horizontal plane through it, which however did not of course affect their generality, as the same effects would necessarily be produced in any plane through the horizontal wire. The secondary circuit consisted of a circle of 35 centimeters radius, of copper wire 2 millimeters in diameter, the circle being broken by an air space capable of variation by means of a micrometer screw.

The circular form was selected for the secondary circuit because the former investigations had shown that the sparking distance was not the same at all points of the secondary, even when the conductor as a whole remained unchanged in position, and with a circular circuit it was easier to bring the air space to any part than if any other form had been used. To attain this object the circle was made movable about an axis passing through its center perpendicular to its plane.

The circuits of the dimensions stated were very nearly in unison, and they were further adjusted by means of little strips of metal soldered to the extremities, and varied in length until the maximum sparking distance was obtained.

We shall follow Dr. Hertz in first considering the subject theoretically, and then examining how far the experimental results are in accordance with the theoretical conclusions. It will be assumed that the E. M. F. at every point is a simple harmonic function of the time, but that it does not undergo reversal in direction, and it will further be assumed

that the oscillations are at any given moment everywhere in the same phase. This will certainly be the case in the immediate neighborhood of the primary, and for the present we shall confine our attention to such points. Let s be the distance of a point, measured along the circuit from the air space of the secondary, and F the component E. M. F. at that point along the circular arc $d\ s$. Then F is a function of s, which assumes its original value after passing once round the circle of circumference S. It may therefore be expanded in the form

$$F=A+B\cos\frac{2\pi s}{S}+\ldots\ldots+B'\sin\frac{2\pi s}{S}+\ldots\ldots$$

The higher terms of the series may be neglected, as the only result of so doing will be that the approximate theory will give an absolute disappearance of sparks where really the disappearance is not quite complete, and indeed the experiments are not delicate enough to enable us to compare their results with theory beyond a first approximation.

The force A acts in the same direction, and is of constant amount at all points of the circle, and therefore it must be independent of the electro static E. M. F., as the integral of the latter round the circle is zero. A, then, represents the total E. M. F. of induction, which is measured by the rate of variation of the number of magnetic lines of force which pass through the circle. If the electro-magnetic field containing the circle is assumed to be uniform, A will therefore be proportional to the component of the magnetic induction perpendicular to the plane of the secondary. It will therefore vanish when the direction of the magnetic induction lies in the plane of the secondary. A will consist of an oscillation, the intensity of which is independent of the position of the air space in the circle, and the corresponding sparking distance will be called a.

The term $B'\sin\frac{2\pi s}{S}$ can have no effect in exciting the fundamental vibration of the secondary, since it is symmetrical on opposite sides of the air space.

The term $B\cos\frac{2\pi s}{S}$ will give force acting in the same direction in the two quadrants opposed to the air space, and will excite the fundamental vibration. In the two quadrants adjacent to the air space it will give a force in the opposite direction, but its effect will be less than that of the former one. For the current is zero at the extremities of the circuit, and therefore the electricity can not move so freely as near the center. This corresponds to the fact, that if a string fastened at each end has its central portion and ends acted on respectively by oppositely directed forces, its motion will be that due to the force at the central portion, which will excite the fundamental vibration if its oscillations are in unison with the latter. The intensity of the vibration will be proportional to B. Let E be the total E. M. F. in the uniform field of the secondary, φ the angle between its direction and the plane of the latter, and θ the angle which its projection on this plane

makes with the radius drawn to the air space. Then we shall have, approximately,

$$F = E \cos \varphi \sin \left(\frac{2 \pi s}{S} - \theta \right)$$

and therefore $$B = -E \cos \varphi \sin \theta$$

B, therefore, is a function simply of the total E. M. F. due both to the electro-static and electro-dynamic actions. It will vanish when $\varphi = 90°$ — that is to say, when the total E. M. F. is perpendicular to the plane of the circle, whatever be the position of the air space on the circle. B will also vanish when $\theta = 0$, — that is to say, when the projection of the E. M. F. on the plane of the circle coincides with the radius through the air space. If the position of the air space on the circle is varied, the angle θ will vary, and therefore also the intensity of the vibration and the sparking distance. The sparking distance corresponding to the second term of the expansion for F can therefore be represented approximately by a formula of the form $\beta \sin \theta$.

Now the oscillations giving rise to sparks of lengths a and $\beta \sin \theta$ respectively are in the same phase. The resulting oscillations will therefore be in the same phase, and their amplitudes must be added together. The sparking distance being approximately proportional to the maximum total amplitude, may therefore also be obtained by adding the sparking distances due to the two oscillations respectively. The sparking distance will therefore be given as a function of the position of the air space on the secondary circuit by the expression $a + \beta \sin \theta$. Since the direction of the oscillation in the air space does not come into consideration we are concerned only with the absolute value of this expression, and not with it sign. The determination of the absolute values of the quantities a and β would involve elaborate theoretical investigations, and is moreover unnecessary for the explanation of the experimental results.

Experiments with the secondary circuit in a vertical plane.—When the circle forming the secondary circuit was placed with its plane vertical, anywhere in the neighborhood of the primary, the following results were obtained:

The sparks disappeared for two positions of the air space, separated by 180°, namely, those in which it lay in the horizontal plane through the primary; but in every other position sparks of greater or less length were observed.

From this it followed that the value of a must have been constantly zero, and that θ was zero when the air space was in the horizontal plane through the primary.

The electro-magnetic lines of force must therefore have been perpendicular to this horizontal plane, and therefore consisted of circles with their centers on the primary, while the electro-static lines of force must have been entirely in the horizontal plane, and therefore this system of lines of force consisted of curves lying in planes passing through the primary. Both of these results are in agreement with theory.

When the air space was at its greatest distance from the plane the sparking distance attained a maximum value of from 2 to 3 millimeters. The sparks were shown to be due to the fundamental vibration, by slightly varying the secondary, so as to throw it out of unison with the primary, when the sparking distance was diminished, which would not have been the case if the sparks had been due to overtones. Moreover, the sparks disappeared when the secondary was cut at its points of intersection with the horizontal plane through the primary, though these would be nodal points for the first overtone.

When the air space was kept at its greatest possible distance from the horizontal plane through the primary, and turned about a vertical axis, the sparking distance attained two maxima at the points for which $\varphi=0$, and almost disappeared at the points for which $\varphi=90°$.

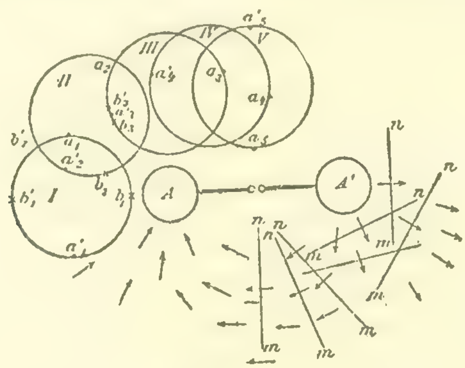

FIG. 8.

The lower half of Fig. 8 shows the different positions of minimum sparking. $A\ A'$ is the primary conductor, and the lines $m\ n$ represent the projections of the secondary circuit on the horizontal plane. The arrows perpendicular to these give the direction of the resultant lines of force. As this did not anywhere vanish in passing from the sphere A to the sphere A', it could not change its sign.

The diagram brings out the two following points:

(1) The distribution of the resultant E. M. F. in the vicinity of the rectilinear vibration is very similar to that of the electro-static E. M. F. due to the action of its two extremities. It should be specially noted that near the center of the primary the direction is that of the electro-static E. M. F., showing that it is more powerful than the electro-dynamic, as required by theory.

(2) The lines of force deviate more rapidly from the line $A\ A'$ than the electro-static lines, though this is not so evident on the reduced scale of the diagram as in the author's original drawings on a much larger scale.

It is due to the components of the electro-static E. M. F. parallel to $A\ A'$ being weakened by the E. M. F. of induction, while the perpendicular components remained unaffected.

Experiments with the secondary circuit in a horizontal plane.—The results obtained when the plane of the secondary was horizontal can best be explained by reference to the upper half of the diagram in Fig. 8.

In the position *I*, with the center of the circle in the line $A\ A'$ produced, the sparks disappeared when the air space occupied either of the b_1 or b'_1, while two equal maxima of the sparking distance were obtained at a_1 and a'_1, the length of the spark in these positions being 2.5 millimeters. Both these results are in accordance with theory.

In position *II* the circle is cut by the electro-magnetic lines of force, and therefore a does not vanish. It will however be small, and we should expect that the expression $a+\beta \sin \theta$ would have two unequal maxima $\beta+a$ and $\beta-a$, both for $\theta=90°$, and having the line joining them perpendicular to the resultant E. M. F., and between these two maxima we should expect two points of no sparking near to the smaller maximum. This was confirmed by the observations.

The maximum sparking distances were 3.5 millimeters at a_2 and 2 millimeters at a'_2. Now with the air space at a_2,—the sphere A being positive,—the resultant E. M. F. in the opposite portion of the circle will repel positive electricity from A, and therefore tend to make it flow round the circle clockwise. Between the two spheres the electro-static E. M. F. acts from A towards A', and the opposite E. M. F. of induction in the neighborhood of the primary acts from A' to A, parallel to to the former, and acting more strongly on the nearer than on the further portion of the secondary, tends to cause a current in the same direction as that due to the former, namely, in a clockwise direction. Thus the resultant E. M. F. is the sum of the two as required by theory, and in the same way it is easily seen that when the air space is at a'_2, the resultant E. M. F. is equal to their difference.

As the position *III* is gradually approached, the maximum disappears, and the single maximum sparking distance a_3 was found to be 4 millimeters in length, having opposite to it a point of disappearance a'_3. In this case clearly $a=\beta$, and the sparking distance is given by the expression $a\ (1+\sin \theta)$. The line $a_3 a'_3$ is again perpendicular to the resultant E. M. F.

As the circle approaches further towards the center of $A\ A'$, a will become greater than β, and the expression $a+\beta \sin \theta$ will not vanish for any value of θ, but will have a maximum $a+\beta$ and a minimum $a-\beta$, and in the experiments it was found that the sparks never entirely disappeared, but varied between a maximum and a minimum, as indicated by theory.

In the position *IV* a maximum sparking distance of 5.5 millimeters was observed at a_4 and a minimum of 1.5 millimeter at a'_4.

In the position *V* there was a maximum sparking distance of 6 millimeters at a_5 and a minimum of 2.5 millimeters at a'_5. In these experiments the air space should be screened off from the primary in the latter positions as well as in the earlier ones, in which it is unavoidable, as otherwise the results would not be comparable.

In passing from the position *III* to the position *V* the line $a a'$ rapidly turned from its position of parallelism to the primary circuit into a position perpendicular to it. In the latter positions the sparking was essentially due to the inductive action, and therefore the author was justified, in his former experiments, in assuming the effect in these positions to be due to induction.

Even in these positions however, the sparking is not totally independent of electro-static action, except when the air space is half way between the maximum and minimum positions, and therefore $\beta \sin \theta = 0$.

Other positions of the secondary circuit.—Dr. Hertz made numerous observations with the secondary circuit in other positions, but in no case were any phenomena observed which were not completely in accordance with theory. As an example of these consider the following experiment:

The secondary was first placed in the horizontal plane in the position *V* (Fig. 8), and the air space was in the position a_5 relatively to the primary. The circle was then turned about a horizontal axis through its center and parallel to the primary, so as to raise the air space above the horizontal plane. During this rotation θ remained equal to 90°, and the value of β remained nearly constant, but a varied approximately in the same ratio as cos Ψ, Ψ being the angle between the plane of the circle and the horizontal, for a is proportional to the number of magnetic lines of force passing through the circle. Let a_0 be the value of a in the initial position, then in the other positions its value would be $a_0 \cos \Psi$, and therefore the sparking distance should be given by the expression $a_0 \cos \Psi + \beta$, in which a_0 was known to be greater than β. This was confirmed by observation, for it was found that as the air space increased its height above the horizontal plane the sparking distance diminished from 6 millimeters down to 2 millimeters, its value when the air space was at its greatest distance above the horizontal plane. During the rotation through the next quadrant the sparking distance diminished almost to zero, and then increased to the smaller maximum of 2.5 millimeters, which it attained when the circle had turned though 180°, and was therefore again horizontal. Similar results were obtained in the opposite order, as the circle was rotated from 180° to 360°. When the circle was kept with the air space at its maximum height above the horizontal plane, and then raised or lowered bodily without rotation, the sparking distance was found to diminish in the former case and to increase in the latter, results completely in accordance with theory.

Forces at greater distances.—Experiments with the secondary at greater distances from the primary are of great importance, as the distribution of E. M. F. in the field of an open circuit is very different according to different theories of electro-dynamic action, and the results

may therefore serve to eliminate some of them as untenable. In making these experiments however, an unexpected difficulty was encountered, as it was found that at distances of from 1 to 1.5 meters from the primary the maximum and minimum, except in certain positions, became indistinctly defined; but when the distance was increased to upwards of 2 meters, though the sparks were then very small, the maximum and minimum were found to be very sharply marked when the sparks were observed in the dark. The positions of maximum and minimum were found to occur with the circle in planes at right angles to each other. At considerable distances the sparking diminished very slowly as the distance was increased. Dr. Hertz was not able to determine an upper limit to the distance at which sensible effects took place, but in a room 14 meters by 12, sparks were distinctly observed when the primary was placed in one corner of the room, wherever the secondary was placed. When however the primary was slightly displaced, no effects could be observed, even when the secondary was brought considerably nearer. The interposition of solid screens between the two circuits greatly diminished the effect.

Dr. Hertz mapped out the distribution of force throughout the room by means of chalk lines on the floor, putting stars at the points where the direction of the E. M. F. became indeterminate. A portion of the diagram obtained in this manner is shown on a reduced scale in Fig. 9,

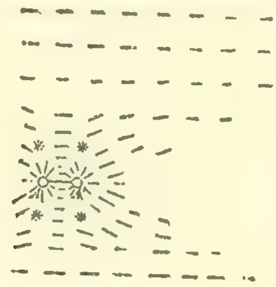

FIG. 9.

with respect to which the following points are note-worthy:

1. At distances beyond 3 meters the E. M. F. is everywhere parallel to the primary oscillation. Within this region, therefore, the electrostatic E. M. F. is negligible in comparison with the E. M. F. of induction. Now all the theories of the mutual action of current elements agree in giving an E. M. F. of induction inversely proportional to the distance, while the electro-static E. M. F., being due to the differential action of the two extremities of the primary, is approximately inversely proportional to the cube of the distance. Some of these theories however are not in accordance with the experimental result that the effect diminishes much more rapidly in the direction of the primary oscillation than in a direction at right angles to it, induced sparks being observed at a distance exceeding 12 meters in the latter direction, while they disappeared at a distance of about 4 meters in the former direction.

2. For distances less than 1 meter (as already proved), the distribution of E. M. F. is practically that of the electro-static E. M. F.

3. There are two straight lines, at all points of which the direction of the E. M. F. is determinate, namely, the line in which the primary oscillation takes place, and the perpendicular to the primary through its middle point. Along the latter the E. M. F. does not vanish at any point, the sparking diminishes gradually as the distance is increased. This again is inconsistent with some of the theories of mutual action of current elements, according to which it should vanish at a certain definite distance. A very important result of the investigation is the demonstration of the existence of regions within which the direction of the E. M. F. becomes indeterminate. These regions form two rings encircling the primary circuit. Since the E. M. F. within them acts very nearly equally in every direction, it must assume different directions in succession, for of course it can not act in different directions simultaneously.

The observations therefore lead to the conclusion that within these regions the magnitude of the E. M. F. remains very nearly constant, while its direction varies through all the points of the compass at each oscillation. Dr. Hertz states that he has been unable to explain this result, as also the existence of overtones, by means of the simplified theory in which the higher terms of the expansion of F are neglected, and he considers that no theory of simple action at a distance is capable of explaining it. If however the electro-static E. M. F. and the E. M. F. of induction are propagated through space with unequal velocities it admits of very simple explanation; for within these annular regions the two E. M. F.'s are at right angles and of the same order of magnitude; they will therefore in consequence of the distance traversed, differ in phase, and the direction of the resultant will turn through all the points of the compass at each oscillation.

This phenomenon appears to him to be the first indication which has been observed of a finite rate of propagation through space of electrical actions, for if there is a difference in the rate of propagation of the electro-static and electro-dynamic E. M. F. one at least of them must be finite.

At the end of the paper in which the preceding experiments are described Dr. Hertz describes some observations which he has made on the conditions at the primary sparking point which affect the production of sparks in the secondary circuit. He finds that illuminating the primary spark diminishes its power of exciting rapid oscillations, the sparks in the secondary being observed to cease when a piece of magnesium wire was burnt, or an arc lamp lighted, near the primary sparking point. The observed effect on the primary sparks is that they are no longer accompanied by a sharp crackling sound as before. The effect of a second discharge is especially noteworthy, and it was found that the secondary sparks could be made to disappear by bringing an insulated

conductor close to the opposed surfaces of the spheres forming the terminals at the primary air space, even when no visible sparking took place between the latter and the insulated conductor. The secondary sparking could also be stopped by placing a fine point close to the primary air space, or by touching one of the opposed surfaces of the terminals with a piece of sealing-wax, glass, or mica. Dr. Hertz states that further experiments have led him to conclude that even in these cases the effect is due to light too feeble to be perceived by the eye, arising from a side discharge. He points out that these effects afford another example of the effects of light on electric discharges, which have been observed by E. Wiedemann, H. Ebert, and W. Hallwachs.

Dr. Hertz's next paper in order of publication in Wiedemann's *Annalen*, "On Some Induction Phenomena Arising from Electrical Actions in Dielectrics" (Wiedemann's *Annalen*, 1888, vol. XXXIV., p. 273), contains an account of some researches undertaken with a view of obtaining direct experimental confirmation of the assumption involved in the most suggestive theory of electrical actions, viz, that of Faraday and Maxwell, that the well-known electro-static phenomena observed in dielectrics are accompanied by corresponding electro-dynamic actions. The method of observation consisted in placing a secondary conductor adjusted to unison, as regards electrical oscillations, with the primary, as near as possible to the former, and in such a relative position that the sparks in the primary produced no sparking in the secondary. As the equilibrium could be disturbed and sparking induced in the secondary by the approach of conductors, it formed a kind of induction balance; but the point of special interest in connection with it was that a similar effect was produced when the conductors were replaced by insulators, provided the latter were of comparatively large size. The observed rapidity of the oscillations induced in the di-electrics showed that the quantities of electricity in motion under the influence of di-electric polarization were of the same order of magnitude as in the case of metallic conductors.

The apparatus employed is shown diagrammatically in Fig. 10, and was supported on a light wooden framework, not shown in the illustration. The primary conductor consisted of two brass plates, AA', with sides 40 centimeters in length, joined by a copper wire 70 centimeters long and half a centimeter in diameter, containing an air space of three-quarters of a centimeter, with terminals formed of polished brass spheres. When placed in connection with a powerful induction coil, oscillations are set up, the period of which, determined by the dimensions of the primary, can be determined to a hundred millionth of a second. The secondary conductor consisted of a circle, 35 centimeters in radius, of copper wire 2 millimeters in diameter, containing an air space, the

length of which could be varied by means of a screw from a few hundredths of a millimeter up to several millimeters. The dimensions stated were such as to bring the two conductors into unison, and secondary sparks up to six or seven millimeters in length could be obtained.

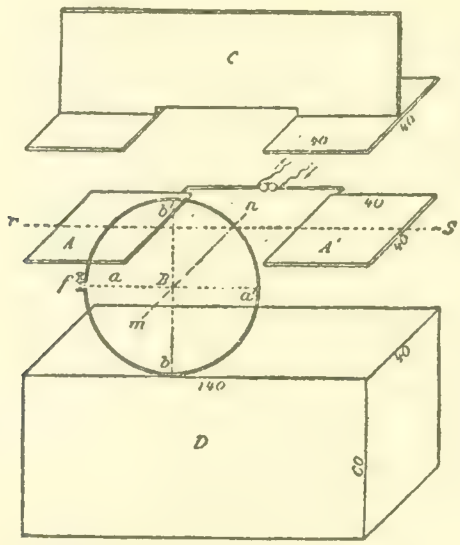

FIG. 10.

The circle was movable about an axis through its center perpendicular to its plane, to enable the position of the air space to be varied. The axis was fixed in the position $m\,n$ in the plane of A and A', and half way between them. The center of the circle was at a distance of 12 centimeters from the nearest points of A and A'.

When f was in either of the positions a or a' lying in the plane of $A\,A'$ no sparking occurred in the secondary, while maximum sparking took place at b and b' 90° from the former positions. The E. M. F. giving rise to the secondary sparks is, as in previous experiments, partly electrostatic and partly electro-magnetic, and the former being the greater will determine the sign of the resultant E. M. F. The oscillations must, for the reason previously explained, be considered as produced in the part of the secondary most remote from the air space. Assuming the E. M. F. and the amplitude of the resulting oscillation to be positive when f is in the position b', they will both be negative when f is at b.

When the circle was slightly lowered in its own plane the sparking distance was increased at b' and diminished at b, and the null points lay at a certain distance below a and a'. The electro-static E. M. F. is scarcely affected by such a displacement, but the integral of the E. M. F. of induction taken round the circle is no longer zero, and therefore gives rise to an oscillation which will be of positive sign whatever be the position of f; for the direction of the resultant E. M. F. of induction is op-

posite to that of the electrostatic E. M. F. in the upper half of the circle, and coincides with it in the lower half where the electrostatic E. M. F. has been assumed to be positive. Since the new oscillation so produced is in the phase as the previously existing one, their amplitudes must be added to give the resultant amplitude, which explains the phenomena.

Effects of the Approach of Conductors.—In making these observations it was found necessary to remove all conductors to a considerable distance from the apparatus, in order to obtain a complete disappearance of sparking at the points a and a'. Even the neighborhood of the observer was sufficient to set up sparking when the air space f was in either of these positions, and the sparks had therefore to be observed from a distance. The conductor used for the experiments was of the form shown at C (Fig. 10), and consisted of thin metal foil. The objects kept in view in selecting the material and dimensions were to obtain a conductor which would give a moderately large effect, and having an oscillation period less than that of the primary.

When the conductor C was brought near to $A\ A'$, it was found that the sparking distance decreased at b and increased at b', and the null points were displaced upwards,—that is, in the direction of C.

From the results of experiments already described it is evident that the effect of displacing $A\ A'$ upwards would be the same, qualitatively, as that of a current in the same direction as that in $A\ A'$ directly above it. The effect produced by the approach of C was the reverse of this, and could be explained by an inductive action, supposing there were a current in C in the opposite direction to that in $A\ A'$, which is exactly what must occur; for the electro-static E. M. F. would give rise to such a current, and since the oscillations in C are more rapid than those of this E. M. F. the current must be in the same phase as the inducing E. M. F. The truth of this explanation was confirmed by the following experiments. The horizontal plates of the conductor C being left in the same position as before, the vertical plate was removed, and successively replaced by wires of increasing length and fineness, in order to lengthen the oscillation period of C. The effect of this was to displace the null points more and more in an upward direction, while at the same time they became less sharply defined, a minimum sparking taking the place of the previous absolute disappearance. The sparking distance at the highest point had previously been much less than at the lowest point, but after the disappearance of the null points it began to increase. At a certain stage the sparking distance at the two positions became equal, and then no definite minimum points could be found, but sparking took place freely at all positions of f. Beyond this stage the sparking distance at the lowest point diminished and very soon two minimum points made their appearance close to it, not clearly defined at first, but gradually becoming more distinct, and at the same time approaching the points $a\ a'$, with which they ultimately

coincided, when the minimum points again became absolute null points. These results are in agreement with the conclusion drawn from the former observations, for as the oscillation period of C approaches that of A A', the intensity of the current in the former increases, but a difference of phase arises between it and the exciting E. M. F. When the two are in unison the current in C attains its maximum, and, as in other cases of resonance, the difference of phase gives rise to a slightly damped oscillation, having a period of about a quarter that of the original one, which makes any interference between the oscillations excited in the circle B by A A' and C respectively impossible. These conditions clearly correspond to the stage at which the sparking distances at b and b' were equal. When the oscillation period of C becomes decidedly greater than that of A A', the amplitude of the oscillation in the former will again diminish, so that the difference in phase between it and the exciting E.M.F. will approach half of the original period. The current in C will therefore always be in the same direction as that in A A', so that interference between the two oscillations excited in B will again become possible, and the effect of C will then be opposite to its original effect. When the conductor C was made to approach A A' the sparks in B became much smaller, which is explained by the fact that its effect will be to increase the oscillation period of A A', and therefore to throw it out of unison with B.

Effects of the approach of dielectrics.—A very rough estimate shows that when a di-electric of large mass is brought near to the apparatus, the quantities of electricity set in motion by di-electric polarization are at least as large as in metallic wires or thin rods. If therefore the action of the apparatus were unaffected by the approach of such masses it would show that in contradiction to the theories of Faraday and Maxwell, no electro-dynamic actions are called into play by means of di-electric polarization, or as Maxwell calls it, electric displacement. The experiments however showed an effect similar to that which would be produced if the di-electric were replaced by a conductor with a very small oscillation period. In the first experiment made, the mass of di-electric consisted of a pile of books, 1.5 meter long, 0.5 meter broad, and 1 meter high, placed under the plates A A'. Its effect was to displace the null points through about 10° towards the pile. A block of asphalt (D, in Fig. 10), weighing 800 kilograms, and measuring 1.4 meter in length, 0.4 meter in breadth, and 0.6 meter in height, was then used in place of the books, the plates being allowed to rest upon it.

The following results were then obtained:

(1) The spark at the highest point of the circle was now decidedly stronger than that at the lowest point, which was nearer to the asphalt.

(2) The null points were displaced through about 23° downwards, that is, in the direction of the block, and at the same time were transformed into mere points of minimum sparking, a complete disappearance being no longer obtainable.

(3) When the plates A A' rested on the asphalt block the oscillation period of the primary was increased, as shown by the fact that the period of B had to be slightly increased in order to obtain the maximum sparking distance.

(4) When the apparatus was moved gradually away from the block its action steadily diminished without changing its character.

(5) The action of the block could be compensated by bringing the conductor C over the plates A A', while they rested on the block, the null points being brought back to a and a' when C was at a height of 11 centimeters above the plates. When the upper surface of the asphalt was 5 centimeters below the plates, compensation was obtained when C was placed at a height of 17 centimeters above them, showing that the action of the di-electric was of the order of magnitude which had been anticipated.

The asphalt contained about 5 per cent. of aluminium and iron compounds, 40 per cent. of calcium compounds, and 17 per cent. of quartz sand. In order to make sure that the observed effects were not due to the conductivity of some of these substances, a number of further experiments were made.

In the first place the asphalt was replaced by a mass of the same dimensions of the so-called artificial pitch prepared from coal, and effects of a similar kind were observed, but slightly weaker, the greatest displacement of the null points amounting to 19°. Unfortunately this pitch contains free carbon, the amount of which it is difficult to determine, and this would have some conductivity.

The experiments were then repeated with a conductor, C, of half the linear dimensions of the former one, and smaller blocks of various substances, on account of the great cost of obtaining large blocks of pure materials. The substances used were asphalt, coal-pitch, paper, wood, sandstone, sulphur, paraffine, and also a fluid di-electric, namely petroleum. With the smaller apparatus it was not possible to obtain quantitative results of the same accuracy as before, but the effects were of an exactly similar character, and left little room for doubt of the reality of the action of the di-electric.

The results might possibly be supposed to be due to a change in the distribution of the electro-static E. M. F. in the neighborhood of the di-electric, but in the first place Dr. Hertz states that he has been unable to explain the details of the observations on this hypothesis, and in the second place it is disproved by the following experiment:

The smaller apparatus was placed with the line $r\,s$ on the upper near corner of one of the large blocks, in which position the di-electric was bounded by the plane of the plates A A' and the perpendicular plane through $r\,s$, both of which are equipotential surfaces, so that if the action were electro-static no effect should be produced by the di-electric. It was found however to produce the same effect as in other positions. It might also be supposed that the effects were due to a slight conduc-

tivity, but this could hardly be the case with such good insulators as sulphur and paraffine. Suppose moreover that the conductivity of the di-electric is sufficient to discharge the plate A in the ten-thousandth of a second, but not much more rapidly. Then, during one oscillation, the plates would lose only the ten-thousandth part of their charge, and the conduction current in the substance experimented on would not exceed the ten-thousandth part of the primary current in A A', so that the effect would be quite insensible.

It was shown in the experiments described in the last section, that when variable electrical forces act in the interior of di-electrics of specific inductive capacity not equal to unity, the corresponding electric displacements produce electro-dynamic effects. In a paper "On the Velocity of Propagation of Electro-Dynamic Actions," in Wiedemann's *Annalen*, 1888, vol. XXXIV, p. 551, Dr. Hertz shows that similar actions take place in the air, which proves, as was previously pointed out, that electro-dynamic action must be propagated with a finite velocity.

The method of investigation was to excite electrical oscillations in a rectilinear conductor in the same manner as in former experiments, and then to produce effects in a secondary conductor by exciting electrical oscillations in it by means of those in the rectilinear conductor, and at the same time by the primary conductor acting through the intervening space. This distance was gradually increased, when it was found that the phase of the vibrations at a distance from the primary lagged behind those in its immediate neighborhood, showing that the action is propagated with a finite velocity, which was found to be greater than the velocity of propagation of electrical waves in wires in the ratio of about 45 to 28, so that the former is of the same order as the velocity of light. Dr. Hertz was unable to obtain any evidence with respect to the velocity of propagation of electro-static actions.

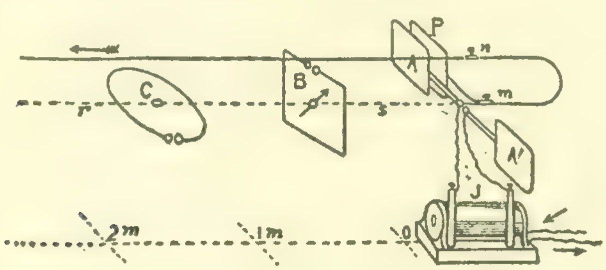

FIG. 11.

The primary conductor A A' (Fig. 11) consisted of a pair of square brass plates with sides 40 centimeters in length, connected by a copper wire 60 centimeters in length, at the middle point of which was an air

space, across which sparks were made to pass by means of powerful discharges from the induction coil *J*. The conductor was fixed at a height of 1.5 meter above the base-plate of the coil, with its plates vertical, and the connecting wire horizontal. A straight line *r s*, drawn horizontally through the air space of the primary and perpendicular to the direction of the primary oscillation, will be called the base-line, and a point in this situated at a distance of 45 centimeters from the air space will be referred to as the null point.

The experiments were made in a large lecture room, with nothing near the base-line for a distance of 12 meters from the primary conductor. The room was darkened during the experiments.

The secondary conductor consisted either of a circular wire *C*, of 35 centimeters radius, or of a square of wire *B*, with sides 60 centimeters long. The primary and secondary air spaces were both capable of adjustment by means of micrometer screws. Both the secondary conductors were in unison with the primary, the (half) vibration period of each being $\frac{1.4}{100,000,000}$ (1.4/hundred-millionths) of a second, as calculated from the capacity and coefficient of self-induction. It is doubtful whether the ordinary theory of electrical oscillations would lead to accurate results under the conditions of these experiments; but as it gives correct numerical results in the case of Leyden-jar discharges, it may be expected to be correct as far as the order of the results is concerned. When the center of the secondary lies in the base-line, and its plane coincides with the vertical plane through the base-line, no sparks are observed in the secondary, the E. M. F. being everywhere perpendicular to the direction of the secondary. This will be referred to as "the first principal position" of the secondary. When the plane of the secondary is vertical and perpendicular to the base-line, the center still lying in the base-line, the secondary will be said to be in its "second principal position." Sparking then occurs in the secondary when its air space is either above or below the horizontal plane through the base-line, but not when it is in this plane. As the distance from the primary was increased the sparking distance was observed to decrease, rapidly at first, but ultimately very slowly. Sparks were observed throughout the whole distance of 12 meters available for the experiments. The sparking in this position is due essentially to the E. M. F. produced in the portion of the secondary remote from the air space. The total E. M. F. is partly electro static and partly electro-dynamic, and the experiments show beyond the possibility of doubt that the former is greater, and therefore determines the direction of the total E. M. F. close to the primary, while at greater distances it is the electro-dynamic E. M. F. which is the greater.

The plane of the secondary was then turned into the horizontal, its center still lying in the base-line. This may be called "the third principal position." When the center of the circular secondary conductor was kept fixed at the null point, and the air space was made to travel

round the circle, vigorous sparking was observed in all positions. The sparking distance attained its maximum length of about six millimeters when its air space was nearest to that of the primary, and its minimum length of about three millimeters when the distance between the two air spaces was greatest. If the secondary had been influenced by the electrostatic force, sparking would only be expected when the air space was close to the base-line, and a cessation of sparks in the intermediate positions. The direction of the oscillation would, moreover, be determined by the direction of the E. M. F. in the portion of the secondary furthest from the air space. There is however superposed upon the electro-statically-excited oscillation a second oscillation due to the E. M. F. of induction, which produces a considerable effect since its integral round the circle (considered as a closed circuit) does not vanish; and the direction of this integral E. M. F. is independent of the position of the air space, opposing the electro-static E. M. F. in the portion of the secondary next to $A A'$, and assisting it in the portion furthest from $A A'$, as explained in a previous paper.

The electro-static and electro-dynamic E. M. F.s therefore act in the same direction when the air space is turned towards the primary conductors, and in opposite direction when the air space is turned away from the primary. In the latter position it is the E. M. F. of induction which is the more powerful, as is shown by the fact that there is no disappearance of sparking in any position of the air space, for when this is 90 degrees to the right or left of the base line it coincides with a node with respect to the electrostatic E. M. F. In these positions the inductive action in the neighborhood of the primary can be observed, independently of the electrostatic action.

Waves in Rectilinear Wires.—In order to produce in a wire by means of the primary oscillations a series of advancing waves of the character required for these experiments, the following arrangements were made: Behind the plate A was placed a plate P of equal size. A copper wire one millimeter in diameter connected P to the point m of the base-line. From m the wire was continued in a curve about a meter in length to the point n, situated about 30 centimeters above the air space, and was then further continued in a straight line parallel to the base-line for such a distance as to obviate all danger of disturbance from reflected waves. In the present series of experiments the wire passed through a window, and after being carried to a distance of about 60 meters was put to earth, and a special series of experiments showed that this length was sufficient. When a wire, bent so as to form a nearly closed circuit with a small air space, was brought near to this straight wire, a series of fine sparks was seen to accompany the discharges of the induction coil. Their intensity could be varied by varying the distance between the plates P and A. The waves in the rectilinear wire were of the same period as that of the primary oscillations, as was proved by their being shown to be in unison with each of the two

secondary conductors previously described. The existence of stationary waves showed that the waves in the rectilinear wire were of a steady character in space as well as in time. The nodal points were determined in the following manner: The further end of the wire was left free, and the secondary conductor was brought near to it, in such a position that the wire lay in its plane, and had the air space turned towards it. As the secondary was moved along the wire, points of no sparking were observed to recur periodically. The distance from the point n to the first of these was measured, and the length of the wire made equal to a multiple of this distance. The experiments were then repeated and it was found that the nodal points occurred at approximately equal intervals along the wire.

The nodes could also be distinguished from the loops in other ways. The secondary conductor was brought near to the wire, with its plane perpendicular to it, and with its air space neither directed completely towards the wire nor completely away from it, but in an intermediate position, so as to produce E. M. F.'s perpendicular to the wire. Sparks were then observed at the nodes, while they disappeared at the loops. When sparks were taken from the rectilinear wire by means of an insulated conductor, they were found to be stronger at the nodes than at the loops; the difference however was small, and was indeed scarcely distinguishable unless the position of the nodes and loops was previously known. The reason that this and other similar methods do not give a well-defined result lies in the fact that irregular oscillations are superposed upon the waves considered; the regular waves however can be picked out by means of the secondary, just as definite notes are picked out by means of a Helmholtz resonator. If the wire is severed at a node, no effect is produced upon the waves in the portion of wire next to the origin; but if the severed portion of wire is left in its place, the waves continue to be propagated through it, though with somewhat diminished strength.

The possibility of measuring the wave-lengths leads to various applications. If the copper wire hitherto used is replaced by one of different diameter, or by a wire of some other metal, the nodal points retain their position unchanged. It follows from this that the velocity of propagation in a wire has a definite value independent of its dimensions and material. Even iron wires offer no exception to this, showing that the magnetic susceptibility of iron does not play any part in the case of such rapid motions. It would be interesting to investigate the behavior of electrolytes in this respect. In their case we should expect a smaller velocity of propagation, because the electrical motions are accompanied by motions of the molecules carrying the electric charges. It was found that no propagation of the waves took place through a tube 10 millimeters in diameter, filled with a solution of sulphate of copper; but this may have been due to the resistance being too high. By the measurement of wave-lengths the relative vibration periods of different primary con-

ductors can be determined, and it therefore becomes possible to compare in this manner the vibration periods of plates, spheres, ellipsoids, &c.

In the experiments made by Dr. Hertz, nodes were very distinctly produced when the wire was severed at a distance of either 8 meters or 5.5 meters from the null point of the base line. In the first case the nodes occurred at distances from the null point of −0.2 meter, 2.3 meters, 5.1 meters, and 8 meters, and in the latter case at distances of −0.1 meter, 2.8 meters, and 5.5 meters. It appears therefore that the (half) wave-length in a free wire cannot differ much from 2.8 meters The fact that the wave-lengths nearest to P were somewhat smaller was to be expected from the influence of the plates and of the curvature of the wire. This wave-length, with a period of 1.4 / hundred-millionths of a second, gives, 200,000 kilometers per second for the velocity of propagation of electrical waves in wires. Fizeau and Gounelle (Poggendorff's *Annalen*, vol. LXXX, p. 158, 1850) obtained for the velocity in iron wires 100,000 kilometers per second, and 180,000 in copper wires. W. Siemens (Poggendorff's *Annalen*, vol. CLVII, p. 309, 1876), by the aid of Leyden-jar discharges, obtained a velocity of from 200,000 to 260,000 kilometers per second in iron wires. Dr. Hertz's result is very nearly the mean of these, from which we may conclude that the order, at any rate, of the vibration period as calculated by him is correct. The value obtained cannot be regarded, independently of its agreement with experimental results otherwise obtained, as a fresh determination of the velocity, since it rests upon a theory which is open to doubt.

Interference of the direct actions with those transmitted through the wire.—If the square circuit B is placed at the null point in the second principal position, with the air space at its highest point, it will be unaffected by the waves in the wire, but the direct action when in this position was found to produce sparks 2 millimeters in length. B was then turned about a vertical axis into the first principal position in which there would be no direct action of the primary oscillation, but the waves in the wire gave rise to sparks, and by bringing P near enough to A, a sparking distance of 2 millimeters could be obtained. In the intermediate positions sparks were produced in both these ways, and it would therefore be possible to get a difference of phase, such that one should either increase or diminish the effect of the other. Phenomena of this nature were, indeed, observed. When the plane of B was in such a position that the normal drawn towards A A' was directed away from that side of the primary conductor on which P was placed, there was more sparking than even in the principal position; but if the normal were directed towards P the sparks disappeared, and only re-appeared when the air space was made smaller. When the air space was at the lowest point of B, the other conditions remaining the

same, the sparks disappeared when the normal was turned away from P. Further variations of the experiment gave results in accordance with these.

It is easily seen that these phenomena were exactly what were to be expected. To fix the ideas, suppose the air space to be at the highest point and the normal directed towards P, as in Fig. 11. Consider what happens at the moment that the plate A has its greatest positive charge. The electro-static, and therefore the total E. M. F., is directed from A towards A'. The oscillation to which this gives rise in B is determined by the direction of the E. M. F. in the lower portion of B. Therefore positive electricity will flow towards A' in the lower portion, and away from A' in the upper portion.

Consider next the action of the waves. As long as A is positively charged, positive electricity will flow from the plate P. This current is, at the moment considered, at its maximum value at the middle point of the first half wave-length. A quarter of a wave-length further from the origin—that is to say, in the neighborhood of the null point—it first changes its direction. The E. M. F. of induction will here therefore impel positive electricity towards the origin. A current will therefore flow round B towards A' in the upper portion and away from A' in the lower portion. The electro-static and electro-dynamic E. M. F.'s are therefore in opposite phases and oppose each other's action. If the secondary circuit is rotated through 90 deg., through the first principal position, the direct action changes its sign, but not so the action of the waves, so that they now tend to strengthen each other. The same reasoning holds when the air space is at the lowest point of B.

Greater lengths of wire were then included between m and n, and it was found that the interference became gradually less marked, until with a length of 2.5 meters it disappeared entirely, the sparks being of equal length whether the normal were directed towards or away from P. When the length of wire between m and n was further increased, the distinction between the different quadrants re-appeared, and with a length of 4 meters the disappearance of the sparks was fairly sharp. The disappearance however then took place (with the air space at the highest point) when the normal was directed away from P, the opposite direction to that in which the disappearance previously took place. With a still further increase in the length of the wire the interference re-appeared and returned to its original direction with a length of 6 meters. These phenomena are clearly to be explained by the retardation of the waves in the wire, and show that here again the direction of motion in the advancing waves changes its sign at intervals of about 2.8 meters.

To obtain interference phenomena with the secondary circuit C in the third principal position, the rectilinear wire must be removed from its original position, and placed in the horizontal plane through C either on the side of the plate A or of the plate A'. Practically it is sufficient

to stretch the wire loosely, and to fix it by means of an insulated clamp on each side of C alternately. It was found that when the wire was on the same side as the plate P the waves in it diminished the previous sparking, and when on the opposite side the sparking was increased, both results being unaffected by the position of the air space in the secondary circuit. Now it has been already pointed out that at the moment when the plate A has its maximum positive charge, and at which therefore the primary current begins to flow from A, the current at the first node of the rectilinear wire begins to flow away from the origin. The two currents therefore flow around C in the same direction when C lies between the rectilinear wire and A and in opposite directions when the wire and A are on the same side of C. The fact that the position of the air space is indifferent confirms the conclusion formerly arrived at, that the direction of oscillation is that due to the electro-dynamic E. M. F. These interferences are also changed in direction when the wire $m\ n$, 1 meter in length, is replaced by a wire 4 meters in length.

Dr. Hertz also succeeded in obtaining interference phenomena when the center of the secondary circuit was not in the base-line, but these results were of no special importance, except that they confirmed the previous conclusions.

Interference phenomena at various distances.—Interference may be produced with the secondary at greater distances than that of the null point, but care must then be taken that the action of the waves in the wire is of about the same magnitude as the direct action of the primary circuit through the air. This can be effected by increasing the distance between P and A.

Now if the velocity of propagation of the electro-dynamic disturbances through the air is infinite, the interference will change its sign at every half-wave length in the wire—that is to say, at intervals of about 2.8 meters. If the velocities of propagation through the air and through the wire are equal, the interference will be in the same direction at all distances. Finally, if the velocity of propagation through the air is finite, but different from the velocity in the wire, the interference will change in sign at intervals greater than 2.8 meters.

The interferences first investigated were those which occurred when the secondary circuit was rotated from the first into the second principal position, the air space being at the highest point. The distance of the secondary from the null point was increased by half-meter stages from 0 up to 8 meters, and at each of these positions an observation was made of the effects of directing the normal towards and away from P respectively. The points at which no difference in the sparking was observed in the two positions of the normal are marked 0 in the table below. Those in which the sparking was least, showing the existence of interference, when the normal was directed towards P are marked +, and those in which the sparking was least when the normal was directed

away from P are marked −. The experiments were repeated with different lengths of wire $m\ n$, varying by steps of half a meter from 1 meter up to 6 meters. The first horizontal line in the table gives the distances in meters of the center of the secondary circuit from the null point, while the first vertical line gives the lengths of the wire $m\ n$, also in meters:

TABLE I.

	0		1		2		3		4		5		6		7		8
100	+	+	0	−	−	−	−	−	0	0	0	0	0	+	+	+	+
150	+	0	−	−	−	−	0	0	0	0	0	+	+	+	+	+	0
200	0	−	−	−	−	−	0	+	+	+	+	+	0	0	0	0	0
250	0	−	−	−	−	0	0	+	+	+	+	0	0	0	0	0	0
300	−	−	−	−	0	+	+	+	+	+	0	0	0	0	−	−	−
350	−	−	0	+	+	+	+	+	+	0	0	0	−	−	−	−	−
400	−	−	0	+	+	−	+	0	0	0	0	−	−	−	−	−	−
450	[illegible]	0	−	+	+	+	+	0	0	0	−	−	−	−	−	−	0
500	−	0	−	+	+	+	0	−	−	−	−	−	0	0	0	0	+
550	0	+	+	[illegible]	+	0	0	−	−	−	−	−	0	0	0	0	+
600	+	+	[illegible]	+	0	0	−	−	−	−	−	0	0	+	+	+	+

An inspection of this table shows, in the first place, that the changes of sign take place at longer intervals than 2.8 meters; and in the second place that the change of phase is more rapid in the neighborhood of the origin than at a distance from it. As a variation in the velocity of propagation is very unlikely, this is probably due to the fact indicated by theory that the electro-static E. M. F., which is more powerful than the electro-dynamic E. M. F. in the neighborhood of the primary oscillation, has a greater velocity of propagation than the latter.

In order to obtain a definite proof of the existence of similar phenomena at greater distances, Dr. Hertz continued the observations in the case of three of the lengths $m\ n$ up to a distance of 12 meters, and the result is given in the table below:

TABLE II.

	0	1	2	3	4	5	6	7	8	9	10	11	12
1[illegible]0	+	0	−	−	0	0	0	+	+	+	+	+	0
250	0	−	−	0	+	+	0	0	0	0	−	−	−
[illegible]	−	0	+	+	0	0	−	−	−	[illegible]	0	0	0

If we make the assumption that at the greater distance it is only the E. M. F. of induction which produces any effect, the experiments would show that the interference of the waves excited by the E. M. F. of induction with the original waves in the wire changes its sign only at intervals of about 7 meters.

In order to investigate the E. M. F. of induction close to the primary oscillation, where the results are of special importance, Dr. Hertz made use of the interferences which were obtained when the secondary circuit was in the third principal position, and the air space was rotated through

90 degrees from the base-line. The direction of the interference at the null point, which has already been considered, was taken as negative, the interference being considered positive when it was produced by the passage of waves on the side of C remote from P, which makes the signs correspond with those of the previous experiments. It must be borne in mind that the direction of the resultant E. M. F. at the null point is opposed to that of the E. M. F. of induction, and therefore the first table would have begun with a negative sign if the electro-static E. M. F. could have been eliminated. The present experiments showed that up to a distance of 3 meters interference continued to occur, and always of the same sign as at the null point. It was unfortunately impossible to extend these observations to a greater distance than 4 meters, on account of the feebleness of the sparks, but the results obtained were sufficient to give distinct evidence of a finite velocity of propagation of the E. M. F. of induction. These observations, like the former ones, were repeated with various lengths of the wire $m\ n$ in order to exhibit the variation in phase, and the results obtained are given in the table below:

TABLE III.

	0	1	2	3	4
100	—	—	—	—	0
150	—	—	0	0	0
200	0	0	0	[illegible]	+
250	0	+	+	+	+
300	+	+	+	+	+
350	+	+	+	+	0
400	+	+	+	+	[illegible]
450	+	+	+	0	0
500	+	+	0	0	0
550	+	0	0	0	—
600	0		—	—	—

which shows that as the distance increases the phase of the interference changes in such a manner that a reversal of sign takes place at intervals of from 7 to 8 meters. This result is further confirmed by comparing the results of Table III with the results for greater distances given in Table II, for in the former series, the effect of the electro-static E. M. F. is eliminated, owing to the special position of the secondary circuit, while in the former it becomes insensible at the greater distances, owing to its rapid decrease with increasing distance. We should therefore expect the results given in the first table for distances beyond 4 meters to follow without a break the results given in Table III for distances up to 4 meters. This was found to be the case, as is evident from inspection of Tables II and III.

To show this more clearly the signs of the interference of the waves, due to the electro-dynamic E.M.F., with the waves in the wire, are collected together in Table IV, the first four columns of which are taken from Table III, and the remaining columns from Table II.

TABLE IV.

	0	1	2	3	4	5	6	7	8	9	10	11	12
100	—	—	—	—	0	0	0	+	+	+	+	+	0
250	0	+	+	+	+	+	0	0	0	0	—	—	—
400	+	+	+	+	0	0		—	—	—	0	0	0

From the results given in this table, the author draws the following conclusions:

(1) The interference does not change its sign at intervals of 2.8 meters. The electro-dynamic actions are therefore not propagated with an infinite velocity.

(2) The interference is not in the same phase at all points, therefore the electro-dynamic actions are not propagated through air with the same velocity as electric waves in wires.

(3) A gradual retardation of the waves in the wire has the effect of displacing a given phase of the interference towards the origin of the waves. The velocity of propagation through the air is therefore greater than through a wire.

(4) The sign of the interference is reversed at intervals of 7.5 meters, and therefore in traversing this distance an electro-dynamic wave gains one length of the waves in the wire.

Thus, while the former travels 7.5 meters, the latter travels 7.5—2.8= 4.7 meters, and therefore the ratio of the velocities is 75: 47, which gives for the half-wave length of the electro-dynamic action 2.8+75/47=4.5 meters. Since this distance is traversed in 1.4/ hundred millionths of a second, the absolute velocity of propagation through the air must be 320,000 kilometers per second. This result can only be considered reliable as far as its order is concerned; but its true value can hardly exceed half as much again, or be less than two-thirds of this amount. In order to obtain a more accurate determination of the true value it will be necessary to determine the velocity of electric waves in wires with greater exactness.

It does not necessarily follow from the fact that in the immediate neighborhood of the primary oscillation the interference changes its sign after an interval of 2.8 meters that the velocity of propagation of the electro-static action is infinite, for such a conclusion would rest upon a single change of sign, which might moreover be explained independently of any change of phase, by a change in the sign of the amplitude of the resultant force at a certain distance from the primary oscillation. Quite independently however of any knowledge of the velocity of propagation of electrostatic actions, there exist definite proofs that the rates of propagation of electro-static and electro-dynamic E. M. F.'s are unequal.

In the first place the total force does not vanish at any point on the base-line. Now, near the primary, the electro-static E. M. F. is the greater,

while the electro-dynamic E. M. F. is the greater at greater distances. There must therefore be some point at which they are equal, and since they do not balance, they must take different times to reach this point.

In the second place, the existence of points at which the direction of the resultant E. M. F. becomes indeterminate does not seem capable of explanation, except on the supposition that the electrostatic and electro-dynamic components perpendicular to each other are in appreciably different phases, and therefore do not compound into a rectilinear oscillation in a fixed direction. The fact that the two components of the resultant are propagated with different velocities is of considerable importance, in that it gives an independent proof that one of them at any rate must have a finite velocity of propagation.

The latest researches of Dr. Hertz on electrical oscillations of which accounts have been published at present, are described in a paper "On Electro-Dynamic Waves in Air, and their Reflections," in Wiedemann's *Annalen*, 1888, vol. XXXIV, p. 609. The author had been endeavoring to find a more striking and direct proof of the finite velocity of propagation of electro-dynamic waves than those which he had hitherto given, for though these are quite sufficient to establish the fact, they can only be properly appreciated by one who has obtained a grasp of the results of the entire series of researches.

In many of the experiments which have been described, Dr. Hertz had noticed the appearance of sparks at points in the secondary conductor, where it was clear from geometrical considerations that they could not be due to direct action, and it was observed that this occurred chiefly in the neighborhood of solid obstacles. It was found moreover, that in most positions of the secondary conductor the feeble sparks produced at a great distance from the primary became considerably stronger in the vicinity of a solid wall, but disappeared with considerable suddenness quite close to the wall. The most obvious explanation of these experiments was that the waves of inductive action were reflected from the wall and interfered with the direct waves, especially as it was found that the phenomena became more distinct when the circumstances were such as to favor reflection to the greatest possible extent. Dr. Hertz therefore determined upon a thorough investigation of the phenomena.

The experiments were made in the Physical Lecture Theatre, which is 15 meters in length, 14 meters in width, and 6 meters in height. Two rows of iron columns, running parallel to the sides of the room, would collectively act almost like a solid wall towards electro-dynamic action, so that the available width of the room was only 8.5 meters. All pendent gas-fittings were removed, and the room left empty, with the exception of wooden tables and forms, which would not exert any ap-

preciable disturbing effect. The end wall, from which the waves were to be reflected, was of solid sandstone, with two doors in it, and the numerous gas pipes attached to it gave it, to a certain extent, the character of a conducting surface, and this was increased by fastening to it a sheet of zinc 4 meters high and 2 meters broad, connected by wires to the gas-pipes and a neighboring water-pipe. Special care was taken to provide an escape for the electricity at the upper and lower extremities of the zinc plate, where a certain accumulation of electricity was to be expected.

The primary conductor was the same that was employed in the experiments last described, and was placed at a distance of 13 meters from the zinc plate, and therefore two meters from the wall at the other end of the room. The conducting wire was placed vertically, so that the E. M. F.'s to be considered increased and diminished in a vertical direction. The center of the primary conductor was 2.5 meters above the floor of the room, which left a clear space for the observations above the tables and benches. The point of intersection of the reflecting surface with the perpendicular from the center of the primary conductor will be called the point of incidence, and the experiments were limited to the neighborhood of this point, as the investigation of waves striking the wall at a considerable angle would be complicated by the differences in their polarization. The plane of vibration was therefore parallel to the reflecting surface, and the plane of the waves was perpendicular to it, and passed through the point of incidence.

The secondary conductor consisted of the circle of 35 centimeters radius, which has been already described. It was movable about an axis through its center perpendicular to its plane, and the axis itself was movable in a horizontal plane about a vertical axis. In most of the experiments the secondary conductor was held in the hand by its insulating wooden support, as this was the most convenient way of bringing it into the various positions required. The results of these experiments however had to be checked by observations made with the observer at a greater distance from the secondary, as the neighborhood of his body exerted a slight influence upon the phenomena. The sparks were distinct enough to be observed at a distance of several meters when the room was darkened, but when the room remained light they were practically invisible even when the observer was quite close to the secondary.

When the center of the secondary was placed in the line of incidence and with its plane in the plane of vibration, and the air space was turned first towards the reflecting wall and then away from it, a considerable difference was generally observed in the strength of the sparks in the two positions. At a distance of about 0.8 meter from the wall the sparks were much stronger when the air space was directed towards the wall, and its length could be adjusted so that while there was a steady stream of sparks when in this position, they disappeared entirely

when the air space was directly away from the wall. These phenomena were reversed at a distance of 3 meters, and recurred, as in the first case, at a distance of 5.5 meters. At a distance of 8 meters the sparks were stronger when the air space was turned away from the wall, as at the distance of 3 meters, but the difference was not so well marked. When the distance was increased beyond 8 meters no further reversal took place, owing to the increase in the direct effect of the primary oscillation and the complicated distribution of the E. M. F. in its neighborhood.

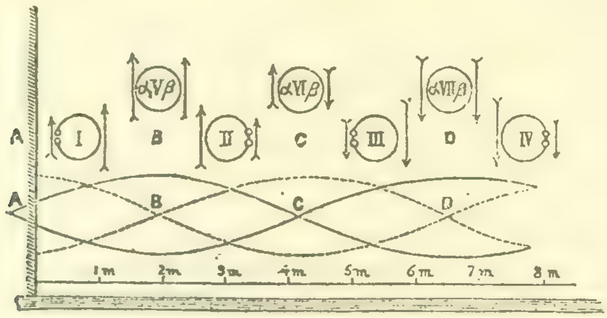

FIG. 12

The positions I, II, and IV, (Fig. 12) of the secondary circle are those in which the sparks were strongest, the distance from the wall being shown by the horizontal scale at the foot. When the secondary circle was in positions V, VI, and VII, the sparks were equally strong in both positions of the air space, and quite close to the wall the difference between the sparking in the two positions again diminished. Therefore the points A, B, C, D in the diagram may in a certain sense be regarded as nodes. The distance between two of these points must not however be taken as the wave half-length, for if all the electrical motions changed their directions on passing through one of these points the phenomena observed in the secondary circuit would be repeated without variation, since the direction of oscillation in the air space is indifferent.

The conclusion to be drawn from the experiments is that in passing any one of these points part of the action is reversed, while another part is not. The experimental results however warrant the assumption that twice the distance between two of these points is equal to the half wave-length, and when this assumption is made the phenomena can be fully explained.

For suppose a wave of E. M. F., with oscillations in a vertical direction, to impinge upon the wall, and to be reflected with only slightly diminished intensity, thus giving rise to stationary waves. If the wall were a perfect conductor, a node would necessarily be formed in its surface, for at the boundary and in the interior of a perfect conductor the E. M. F. must be infinitely small. The wall cannot however be considered as a perfect conductor, for it was not metallic throughout, and the

portion which was metallic was not of any great extent. The E. M. F. would therefore have a finite value at its surface, and would be in the direction of the impinging waves. The node, which in the case of perfect conductivity would occur at the surface of the wall, would therefore actually be situated a little behind it, as shown at A in the diagram. If then twice the distance A B—that is to say, the distance A C—is half the wave-length the steady waves will be as represented by the continuous lines in Fig. 12. The E. M. F.'s acting on each side of the circles, in the positions I, II, III, and IV, will therefore at a given moment be represented in magnitude and direction by the arrows on each side of them in the diagram. If therefore in the neighborhood of a node the air space is turned towards the node, the strongest E. M. F. in the circle will act under more favorable conditions against a weaker one under less favorable conditions. If however the air space is turned away from the node, the stronger E. M. F. acts under less favorable conditions against a weaker one under more favorable conditions. In the latter case the resultant action must be less than in the former, whichever of the two E. M. F.'s has the greater effect, which explains the change of sign of the phenomenon at each quarter wave-length.

This explanation is further confirmed by the consideration that if it is the true one, the change of sign at the points B and D must take place in quite a different manner from that of the point C. The E. M. F.'s, acting on the secondary circle, in the positions V, VI, and VII, are shown by the corresponding arrows, and it is clear that in the positions B and D, if the air space is turned from one side to the other, the vibration will change its direction round the circle, and therefore the sparking must during the rotation vanish either once or an uneven number of times. In the position C, however, the direction of vibration remains unaltered, and therefore the sparks must disappear an even number of times, or not at all.

The experiments showed that at B and D the sparking diminished as the air space receded from a, vanished at the highest point, and again attained its original value at the point β. At C, on the other hand, the sparking continued throughout the rotation, being a little stronger at the highest and lowest points. If then there is any change of sign in the position C, it must occur with very much smaller displacements than in other positions, so that in any case there is a distinction such as required between this and the other two cases.

Another very direct proof of the truth of Dr. Hertz's presentation of the nature of the waves was obtained. If the secondary circle lies in the plane of the waves instead of in the plane of vibration, the E. M. F. must be equal at all points of the circle, and for a given position of the air space, the sparking must be directly proportional to its intensity. When the experiment was made it was found, as expected, that at all distances the sparking vanished at the highest and lowest points of the circle, and attained a maximum value at the points in the horizontal plane through the point of incidence.

The air space was then placed at such a point and close to the wall and was then moved slowly away from the wall, when it was found that while there was no sparking quite close to the metal plate, it began at a very small distance from it, rapidly increased, reached a maximum at the point B, and then diminished again. At C the sparking again became excessively feeble, and increased as the circle was moved still further away. The sparking continued steadily to increase after this, as the motion of the circle was continued in the same direction, owing, as before, to the direct action of the primary oscillation.

The curves shown by the continuous lines in Fig. 12 were obtained from the results of these experiments, the ordinates representing the intensity of the sparks at the distances represented by the corresponding abscissæ.

The existence in the electrical waves of nodes at A and C, and of loops at B and D, is fully established by the experiments which have been described; but in another sense the points B and D may be regarded as nodes, for they are the nodal points of a stationary wave of magnetic induction which, according to theory, accompanies the electrical wave and lags a quarter wave-length behind it.

This can easily be shown to follow from the experiments, for when the secondary circle is placed in the plane of vibration with the air space at its highest point, there will be no sparking if the E. M. F. is uniform throughout the space occupied by the secondary. This can only take place if the E. M. F. varies from point to point of the circle, and if its integral round the circle differs from zero. This integral is proportional to the number of magnetic lines of force passing backwards and forwards across the circle, and the intensity of the sparks may be considered as giving a measure of the magnetic induction, which is perpendicular to the plane of the circle. Now in this position vigorous sparking was observed close to the wall, diminishing rapidly to zero as the point B was approached, then increasing to a maximum at C, falling to a well-marked minimum at D, and finally increasing continuously as the secondary approached still nearer to the primary. If the intensities of these sparks are taken as ordinates, positive and negative, and the distances from the wall as abscissæ, the curve shown by the dotted lines in Fig. 12 is obtained, which therefore represents the magnetic waves.

The phenomena observed in the first series of experiments described in this paper may therefore be regarded as due to the resultant electric and magnetic actions. The former changes sign at A and C, the latter at B and D, so that at each of these points one part of the action changes sign, while the other does not, and therefore the resultant action, which is their product must change sign at each of these points, as was found to be the case.

When the secondary circle was in the plane of vibration the sparking

in the vicinity of the wall was observed to be a maximum on the side towards the wall, and a minimum at the opposite side, and as the circle was turned from one position to the other there was found to be no point at which the sparks disappeared. As the distance from the wall was increased, the sparks on the remote side gradually became weaker, and vanished at a distance of 1.08 meters from the wall. When the circle was carried further in the same direction, the sparks appeared again on the side remote from the wall, but were always weaker than on the side next to it; the sparking however no longer passed from a maximum to a minimum merely, but vanished during the rotation once in the upper and once in the lower half of the circle. The two null points gradually receded from their original coincident positions, until at the point B they occurred at the highest and lowest points of the circle. As the circle was moved further in the same direction, the null points passed over to the side next to the wall, and approached each other again, until when the center was at a distance of 2.35 meters from the wall the two null points were again coincident. B must be exactly half-way between this point and the similar point previously observed, which gives 1.72 meters as the distance of B from the wall, a result which agrees, within a few centimeters with that obtained by direct observation. Moving further in the direction of C, the sparking at different points of the circle became more nearly equal, until at C it was exactly so. In this position there was no null point, and as the distance was further increased the phenomena recurred in the same order as before.

Dr. Hertz found that the position of C could be determined within a few centimeters, the determinations of its distance from the wall varying from 4.10 to 4.15 meters; he gives its most probable value as 4.12 meters. The point B could not be observed with any exactness, the direct determinations varying from 6 to 7.5 meters as its distance from the wall. It could however be determined indirectly, for the distance between B and C being found to be 2.4 meters, taking this as the true value, A must have been 0.68 meter behind the surface of the wall, and 6.52 meters in front of it. The half-wave length would be 4.8 meters, and by an indirect method it was found to be 4.5 meters, so that the two results agree fairly well. Taking the mean of these as the true value, and the velocity of light as the velocity of propagation, gives as the vibration period of the apparatus 1.55/ hundred-millionths of a second, instead of 1.4/ hundred-millionths, which was the theoretically calculated value.

A second series of experiments were made with a smaller apparatus, and though the measurements could not be made with as much exactness as those already described, the results showed clearly that the position of the nodes depends only on the dimensions of the conductors and not on the material of the wall.

Dr. Hertz states that after some practice he succeeded in obtaining

indications of reflection from each of the walls. He was also able to obtain distinct evidence of reflection from one of the iron columns in the room, and of the existence of electro-dynamic shadows on the side of the column remote from the primary.

In the preceding experiments the secondary conductor was always placed between the wall and the primary conductor;—that is to say, in a space in which the direct and reflected rays were travelling in opposite directions, and gave rise to stationary waves by their interference.

He next placed the primary conductor between the wall and the secondary, so that the latter was in a space in which the direct and reflected waves were traveling in the same direction. This would necessarily give rise to a resultant wave, the intensity of which would depend on the difference in phase of the two interfering waves. In order to obtain distinct results it was necessary that the two waves should be of approximately equal intensities, and therefore the distance of the primary from the wall had to be small in comparison with the extent of the latter, and also in comparison with its distance from the secondary.

To fulfill these conditions the secondary was placed at a disadvantage of 14 meters from the reflecting wall, and therefore about 1 meter from the opposite one, with its plane in the plane of vibration, and its air space directed towards the nearest wall, in order to make the conditions as favorable as possible for the production of sparks. The primary was placed parallel to its former position, and at a perpendicular distance of about 30 centimeters from the center of the reflecting metallic plate. The sparks observed in the secondary were then very feeble, and the air space was increased until they disappeared. The primary conductor was then gradually moved away from the wall, when isolated sparks were soon observed in the secondary, passing into a continuous stream when the primary was between 1.5 and 2 meters from the wall;—that is, at the point B. This might have been supposed to be due to the decrease in the distance between the two conductors, except that as the primary conductor was moved still further from the wall the sparking again diminished, and disappeared when the primary was at the point C. After passing this point the sparking continually increased as the primary approached nearer to the secondary. These experiments were found to be easy to repeat with smaller apparatus, and the results obtained confirmed the former conclusion, that the position of the nodes depends only on the dimensions of the conductor, and not on the material of the reflecting wall.

Dr. Hertz points out that these phenomena, which are exactly analogous to the acoustical experiment of approaching a vibrating tuning-fork to a wall, when the sound is weakened in certain positions and strengthened in others, and also to the optical phenomena illustrated in Lloyd's form of Fresnel's mirror experiments; and as these are accepted as arguments tending to prove that sound and light are due to vibration, his

investigations give a strong support to the theory that the propagation of electro-magnetic induction also takes place by means of waves. They therefore afford a confirmation of the Faraday-Maxwell theory of electrical action. He points out however that Maxwell's, in common with other electrical theories, leads to the conclusion that electricity travels through wires with the velocity of light, a conclusion which his experiments show to be untrue. He states that he intends to make this contradiction between theory and experiment the subject of further investigation.

REPETITION OF HERTZ'S EXPERIMENTS,

AND DETERMINATION OF THE DIRECTION OF THE VIBRATION OF LIGHT.*

By FREDERICK T. TROUTON.

Since last October (1888), Professor Fitzgerald and I have been repeating some of Professor Hertz's experiments, as occasion allowed, and it may not be without interest at the present time to give a short account of our work.

The first experiment tried was the interference of direct electro-magnetic radiation with that reflected from a metallic sheet. This experiment is analogous to that known in optics as "Lloyd's experiment."

The radiation was produced by disturbances caused in the surrounding space by electrical oscillations in a conductor. It was arranged in this wise. Two thin brass plates, about 40 centimeters square, were suspended by silk threads at about 60 centimeters apart, so as to be in the same plane. Each plate carried a stiff wire furnished at the end with a brass knob. The knobs were about 3 millimeters apart, so that

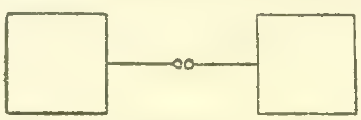

FIG. 1.

on electrifying one plate a spark could easily pass to the other. This spark, as is well known, consists not simply of a transference of half the electricity of the first plate to the second—though this, which is the final state, is all that is observable by ordinary experimental methods—but the whole charge passes across to the second plate, then returns, and so on, pendulum-fashion, the moving part of the charge becoming less each time, till finally brought to rest, the energy set free at sparking being converted partly into heat in the wire and air break, partly into radiation into space, or in terms of action at a distance in inducing currents in other bodies.

The time taken by the charge to pass over to the second plate and to return, is a definite thing for a given sized arrangement, and depends on the connection between them. If C be the capacity of the plates, and I the self-induction of the connection, the time of each complete oscillation equals $2\pi\sqrt{(CI)}$. The time in the case of the particular ar-

* From *Nature*, Feb. 21, 1889, vol. XXXIX, pp. 391-393.

rangement used is (speaking roughly) about the $\frac{1}{30,000,000}$ (one/thirty-millionth) of a second.

If there be conductors in the neighborhood of this "vibrator," currents will as usual be induced in each on every passage of the charge between the plates, each passage serving simply as a primary current.

Now, speaking briefly, the whole object of the experiment is to find out if these induced currents take place simultaneously in conductors situated at various distances from the primary current, and if not, to determine the delay. In order to do this we must, in the first place, be possessed of some means of even ascertaining that these currents occur, all ordinary methods being inadequate for detecting currents lasting only for such exceedingly short periods as these do. By devising how to determine the existence of these currents, Hertz made the experiment possible.

His method depends on the principle of resonance, previously suggested by Fitzgerald, and his current-observing apparatus is simply a conductor, generally a wire bent into an unclosed circle, which is of such a length that if a current be induced in it by a passage of a charge across the "vibrator" the return current or rush back of the electricity thus produced in the ends of the wire occurs simultaneously with the next impulse, due to the passage back across the "vibrator."

In this way the current in the "resonator" increases every time, so that at last the end charges, which are always of opposite sign, grow to be so great that sparks will actually occur if the ends of the wire are brought near together. Thus Hertz surmounted the difficulty previously experienced by Fitzgerald when proposing electro-magnetic interference experiments.

The time of vibration in this circle is, as before, $2\pi\sqrt{(CI)}$, but on account of difficulties in calculating these quantities themselves, the length of the wire is most readily found by trial. To suit the "vibrator" we used, it was about 210 centimeters of wire No. 17. The ends of the wire were furnished with small brass knobs, which could be adjusted as to distance between them, by a screw arrangement, the whole being mounted on a cross of wood for convenience in carrying about.

At first sight the simplest "resonator" to adopt would seem to be two more plates arranged similarly to the "vibrator," but it will be seen on consideration that it would not do, because no break for seeing the sparking could be put between the plates, for if it were, the first induced current would be too feeble to jump the break, so that the re-enforcement stage could never begin.*

The charging of the "vibrator" was effected by connecting the terminals of an induction-coil with the plates. In this way a continuous shower of sparks could be obtained in the resonating circle.

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* However, two pairs arranged in line, the pairs connected by a wire, could probably be got to spark between the center plates.

The circle in the interference experiment was held in the horizontal plane containing the axis of the "vibrator," the ends of the circle of wire being in such a position that a line joining the knobs was at right angles to the "vibrator." In this position only the magnetic part of

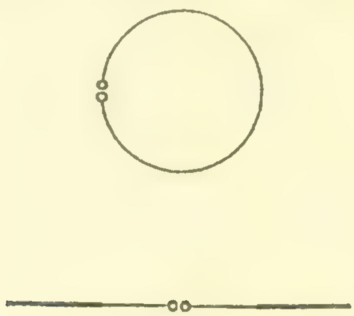


FIG. 2.

the disturbance could affect the circle, the "magnetic lines of force," which are concentric circles about the axis of the "vibrator," passing through the "resonator" circles.

When the knobs of the circle are brought round through 90°, so as to be parallel to the "vibrator," the electric part of the disturbance comes into play, the electric lines of force being, on the whole, parallel to the axis of the "vibrator." The electric action alone can cause a forced vibration in the knobs, even when the connecting wire is removed, if placed fairly close to the "vibrator."

Again, if the knobs be kept in this position, but the circle be turned through 90°, so that its plane is vertical, only the electric part can act, the magnetic lines of force just grazing the circle. In this way the disturbance can be analyzed into its magnetic and electric constituents.

Lastly, if the knobs be in the first position, while the circle is vertical, there will be no action.

To exhibit these alone forms an interesting set of experiments. It also makes a very simple and beautiful experiment to take a wire twice as long and fix it instead of the first, but with two turns instead of one; no sparking is then found to occur. This is of course quite opposed to all ordinary notions, double the number of turns being always expected to give double the electro-motive force. In this way the reality of the resonance is easily shown.

Interference experiment.—The sparking of course becomes less intense as the resonator is carried away from the "vibrator," but by screwing the knobs nearer together it was possible to get sparks at 6 and 7 meters away. On bringing a large sheet of metal (3 meters square, consisting of sheet zinc) immediately behind the "resonator," when in sparking position, the sparking increased in brightness, and allowed the knobs to be taken further apart without the sparking ceasing; but when the sheet was placed at about 2.5 meters further back, the spark-

ing ceased, and could not be obtained again by screwing up the knobs. On the other hand, when the sheet was placed at double this distance (about 5 meters), the sparking was slightly greater than without the sheet.

Now these *three* observations can only be explained by the interference and re-enforcement of a direct action of the "vibrator" with one reflected from the metallic sheet, and in addition by the supposition that the action spreads out from the vibrator at a finite velocity. According to this explanation, in the first position the reflected part combines with the direct and reinforces its effects. In the second position (that of no sparking), the reflected effect in going to the sheet and returning has taken half the time of a complete vibration of the "vibrator," and so is in the phase opposite to the incident wave, and consequently interferes with it.

If it were possible to tell the direction of the current in a "resonator" at any moment, then, by employing two of them, and placing one just so much beyond the other that the currents induced in them were always in opposite directions, we would obtain directly the half-way length. Now by reflection, we virtually are put in possession of two "resonators," which we are enabled to place at this distance apart, although unable to tell more than whether there be a current or not.

The distance from the position of interference to the sheet is a quarter of the wave-length, being half the distance between these simultaneous positions of opposite effects.

In the third position, the reflected wave meets the effect of the next current but one, in the "vibrator," after the current it itself emanated from, and since these two currents are in the same direction, their effects re-enforce each other in the "resonator." This occurs at half the wave-length from the sheet.

The first two observations alone could be explained by action at a distance, by supposing the currents induced in the metallic sheet to oppose the direct action in the "resonator" everywhere, and by also supposing that in the immediate neighborhood of the sheet, the direct action is overmastered by that from the sheet, while at 2.5 meters away the two just neutralize each other.

On this explanation, at all distances further the direct action should be opposed by that from the sheet, so that the fact of being increased at 5 meters upsets this explanation. Again, behind the sheet, evidently on this supposition, the two actions should combine so as to increase the sparking, but instead of this the sparking was found to cease on placing the sheet in front of the "resonator."

In performing these experiments, the "resonator" circle was always placed in the position in which only the magnetic part of the disturbance had effect. Hertz has also used the other positions of the resonating circle, whereby he has observed the existence of an electric disturbance coincident with the magnetic one, the two together forming the complete electro-magnetic wave.

Ordinary masonry walls were found to be transparent to radiation of this wave-length (that is, of about 10 meters), and some visitors to the opening meeting of the Dublin University Experimental Society, last November, were much astonished by seeing the sparking of the resonating circle out in the College Park, while the vibrator was in the laboratory.

Attempts were first made last December to obtain reflection from the surface of a non-conductor, with the hope of deciding by direct experiment whether the magnetic or electric disturbance was in the plane of polarization; that is, to find out whether the "axis of the vibrator" should be at right angles to the plane of reflection or in it, when at the polarizing angle, for obtaining a reflected radiation. It is to be observed that in these radiations the electric vibration is parallel to the "axis of the vibrator" while the magnetic is perpendicular to it, and that they are consequently polarized in the same sense as light is said to be polarized.

Two large glass doors were taken down and used for this purpose, but without success; and until lately, when reflection from a wall was tried, the experiment seemed unlikely to be successful.

In working with the glass plate, the resonator circle was first placed so that the "vibrator" had no effect on it. Then the glass plate was carried into position for reflection, but without result, though even the reflection from the attendants moving it was amply sufficient to be easily detected.

To obviate a difficulty arising from the fact that the wave was divergent, we decided to try Hertz's cylindrical parabolic mirrors, for concentrating the radiation. Two of these were made with sheets of zinc nailed to wooden frames, cut to the parabolic shape required.

In the "focal line" (which was made 12.5 centimeters from the vertex) of one of these, a "vibrator" was placed, consisting of two brass cylinders in line, each about 12 centimeters long and 3 centimeters in diameter, rounded at the sparking ends.

In order that the "resonator" wire may lie in the "focal line" of the receiving mirror, it has to be straight; this necessitates having two of them. They each consist of a thick wire 50 centimeters long, lying in the "focal line," and of a thin wire, 15 centimeters long, attached to one end at right angles, and which passes out to the back of the mirror through a hole in the zinc, where the sparking can be viewed, without obstructing the radiation in front. The total length of each "resonator" is about two wave-lengths, the wave-length being about 33 centimeters, so that it may be that there are two vibrating segments in each of these "resonators."

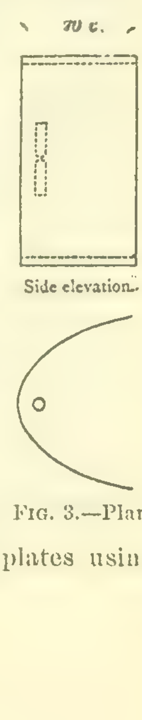


FIG. 3.—Plan.

With this apparatus it is possible to deal with definite angles of incidence. No effect was obtained with glass plates using

these mirrors, whether the "vibrator" was perpendicular to the plane of reflection or in it. But with a wall 3 feet thick reflection was obtained, when the "vibrator" was perpendicular to the plane of reflection; but none, at least at the polarizing angle,* when turned through 90° so as to be in it.

This decides the point in question, the magnetic disturbance being found to be in the plane of polarization, the electric at right angles. Why the glass did not reflect was probably due to its thinness, the reflection from the front interfering with that from the back, this latter losing half a wave-length in reflection at a surface between a dense and a rare medium; and, as Mr. Joly pointed out, is in that case like the black spot in Newton's rings, or more exactly so, the black seen in very thin soap-bubbles.

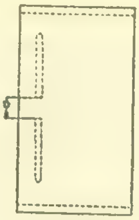


FIG. 4.

Hertz has pointed out several important things to be guarded against in making these experiments. Ultra-violet light, for example, falling on the "vibrator," prevents it working properly, the sparking in the resonator ceasing or becoming poor. Also the knobs of the "vibrator" must be cleaned of burnt metal, and polished every quarter of an hour at least, to prevent a like result.

Both these effects probably arise, as suggested by Mr. Fitzgerald, from a sort of initial brush discharging (either ultra-violet light or points being capable of doing this), which prevents the discharging impulse being sufficiently sudden to start the oscillation in the "vibrator." For to start a vibration, the time of impulse must be short compared with the time of oscillation. These precautions therefore become especially needful when working with small-sized "vibrators." Possibly charging the "vibrator" very suddenly, after the manner of one of Dr. Lodge's anti-lightning-rod experiments, would save the irksome necessity of repeatedly cleaning the knobs of the "vibrator."

Several important problems seem to be quite within reach of solution by means of these Hertzian waves, such for instance as dispersion. Thus it could be tried whether placing between the reflector and the "resonator" conducting bodies of nearly the same period of vibration as the waves used would necessitate the position of the "resonator"

* Slight reflection was obtained at an incidence of 70°.

being changed so as to retain complete interference. Or again, whether interspersing throughout the mass of a large Hertzian pitch-prism, conductors with nearly the same period would alter the angle of refraction. In some such way as this, anomalous dispersion, with its particular case of ordinary dispersion, may yet be successfully imitated.

The determining the rate of propagation through a large tile, or sheet of sandstone, could be easily made by means of the interference experiment, by placing it between the screen and the "resonator."

EXPERIMENTS ON ELECTRO-MAGNETIC RADIATION,

INCLUDING SOME OF THE PHASE OF SECONDARY WAVES.*

In continuation of some experiments which were described in *Nature*, vol. XXXIX, p. 391 ("Repetition of Hertz's Experiments and Determination of the Direction of the Vibration of Light"), attempts were made to obtain periodic reflection of electric radiation from plates of different thicknesses, analogous to Newton's rings, with the view of further identifying these radiations with "light."

It was there described how a sheet of window-glass refused to reflect the Hertzian waves, but how a masonry wall reflected them readily. The non-reflection from the thin sheet is due to the interference of the reflected waves from each side which takes place owing to a change of phase of half a period on reflection at the second surface, as in the black spot of Newton's rings.

By making the reflection plate such a thickness that the reflection from the back has to travel half a wave-length farther than that from the front, the two reflections ought to be in accordance, for they differ by a whole period, half arising from difference in path, and half from change of phase on reflection; but if the difference in paths were made a whole wave-length by doubling the thickness of the plate, there ought again to be interference, and so on.

The first plan tried with this end in view, was to fill a large wooden tank to different depths with water or other liquids. On gradually filling the tank reflection should be obtained, and at a certain depth equal to $\frac{1}{4}(\lambda \sec r) \div \mu$, reach a maximum; further addition of the liquid then should diminish the reflection, and at double the above depth the reflection should reach a minimum, the two waves interfering.

The mirrors for concentrating the radiation had for this purpose to

* From *Nature*, August 22, 1889, vol. XL, pp. 398–400.

be suspended over the tank as shown in the figure. The tank was first tried empty, but unfortunately the wooden bottom was found to reflect,

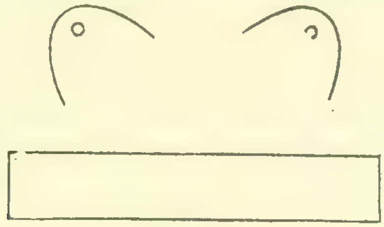


FIG. 5.

thus it was useless for the purpose intended. I then tried what ought to have been tried before constructing the tank, namely—whether ordinary boards, such as flooring, reflected. The floor was found to reflect readily. This was attributed to moisture in the wood causing it to conduct, specially as wood was found not to polarize by reflection. Experiments were then undertaken to determine if water reflected, even though in thin sheets. A large glass window was placed beneath the mirrors and flooded with water; this was found to reflect well, both when the mirrors were in the position shown and when rotated to the position "at right angles." Thus water also acts like a metal, reflecting the radiation however polarized. The glass had to be hardly more than damp to get some reflection.

The wooden tank being unsuitable, a glass tank was thought of, but was given up for solid paraffine, which, being in slabs, could be easily built up into a vertical wall of any desired thickness. Through the kindness of Mr. Rathborne a large quantity of this was lent for the purpose.

A thin sheet of paraffine about 2 centimeters thick was found not to reflect, as was expected. Next a wall 13 centimeters thick (180 centimeters long, 120 centimeters high) was tried, and found to reflect, this being the thickness required in order to add another half period to the retardation of the wave reflected from the back at an incident angle of 55°, the wave-length being taken as 66 centimeters, and the index of refraction being taken as 1.51, the square root of 2.29, the value taken as the specific inductive capacity of paraffine.

Then a wall twice the thickness was tried, but it also reflected, contrary to expectation. While in doubt as to the cause of this, it was decided to make a determination by direct experiment of the index of refraction of paraffine for these waves, by a method suggested in *Nature* (vol. xxxix, p. 393), which consists in interposing a sheet or wall of paraffine between the resonator and the metallic reflection in the Hertzian experiment of loops and nodes which are formed by the interference of the reflected wave with the direct radiation; the ratio of the velocity in the wall to that in the air being easily found from the observed shifting of the loops and nodes towards the screen.

In this way the index of refraction for the radiation of the period employed was found to be about 1.8, so that the paraffine walls which had been used were too thick, the proper thickness being about 10 and 20 centimeters—exactly so for an incident angle of 51°. On making this alteration I fancied I could detect a slight difference between the reflections from the thick and thinner walls; still the difference was not sufficient to be at all satisfactory. The nature of the observing apparatus makes it almost impossible to say if the reflection on one occasion is more intense or less so than on another so long as sparks can be obtained. This is due to the sparking-point in the receiving apparatus continually requiring re-adjustment when working with small sparks, as the distance between them changes either from shaking or from the points getting burnt up.* Dust, and moisture from the observer's breath, are also troublesome. Thus it might be quite possible that the points had always to be much closer with the 20-centimeter wall than with the 10-centimeter wall in order to get sparks, and yet the difference escape detection; the thing observed being whether sparks can be obtained or not, the eye being incapable of comparing with any degree of accuracy the intensity of light on one occasion with that on another.

However, if it had been possible to suddenly change the wall, while viewing the sparking, from being 10 to 20 centimeters, it would have been easy to detect any difference which might have existed, but unfortunately it took some little time to alter the wall.

In order to obviate this difficulty the following device was resorted to with the object of showing that there was a difference in the behavior of the wall when 10 centimeters thick to its behavior when 20 centimeters thick. (For at the time I did not see that the experiment was inconclusive, the effects observed being the same whether the back reflected at all or not.) A *small* sheet of zinc was placed at the back of the wall, and the effect on the sparking observed while an attendant suddenly removed or again replaced the zinc. It was supposed that when the wall was 20 centimeters thick, and there was sparking, that on suddenly placing the zinc on the back the sparking would increase, owing to the phase of the reflection from the back being half a period different from that of the reflection from the zinc; but when the wall was 10 centimeters thick that the presence of the zinc would diminish the sparking.

It was with no little surprise that the reverse was observed. That is to say, placing a sheet of zinc about 30 centimeters square on the back of the wall actually aided the reflection from the back so as to diminish the sparking with the 20-centimeter wall, but increasing it with the 10-centimeter wall. This observation made it look as if it must be on the first reflection from the paraffine (that is to say, on

* With *very small* sparks the thermal expansion must be counteracted by unscrewing.

passing from a rare to a dense medium) that the "change of phase" occurs, and not at the back (at a reflection from a dense to a rare medium), as is ordinarily supposed. For Hertz's experiment of loops and nodes showed that there was no change of phase on metallic reflection, that is, of the *magnetic* displacement; there is a change of phase of the *electric* displacement. It is important to bear in mind that the electric loop and the magnetic node occurred at the same place, and of course so too the electric node and the magnetic loop.

In order to investigate this, attempts were made to obtain Hertz's loops and nodes off a paraffine wall as reflector, but no reflection could be discovered, the intensity of the vertically reflected rays being insufficient. However, by inclining the incident radiation to an angle of 57°, the intensity of the reflection was found to be amply sufficient.

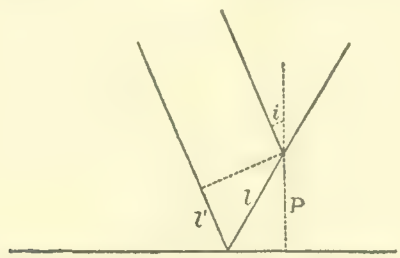


FIG. 6.

With a circular resonator, which is for these waves about 10 centimetres in diameter, sparks were obtained close to the reflector, the circle being held at right angles to the wall so as to be equally inclined to both direct and reflected radiation, and this was confirmed by a straight resonator giving none there. At 30 centimeters from the wall* there was interference with the circle, and vigorous sparking with the straight resonator. This being about the right distance for the loop to be from the reflector at an incident angle of 57°,

$$\tfrac{1}{2}\lambda = l + l' = p \sec i(1 + \cos 2i) = 2p \cos i.$$

Thus there is no doubt that it is on the second reflection that the change of phase occurs.

Here then was a difficulty; the small sheet of zinc at the back of the paraffin undoubtedly reflected with a change of phase, while, according to the Hertzian experiment, metallic reflection is unaccompanied by change of phase. On mentioning this to Professor Fitzgerald, he pointed out to me its complete agreement with wave theory. For by considering the secondary waves produced by dividing up a primary wave with reference to any point into half-period zones, it can be seen that the effect of the primary is equivalent to half of that arising

* It would occur at about 17 centimeters on vertical reflection. This experiment was also tried with a metallic reflector.

from the central circle, and in consequence is half a period behind the phase which would be at the point if an infinitesimal portion of the center alone acted. For the effect of each ring can be considered as destroyed by half the effect of its two neighbors, and thus half the

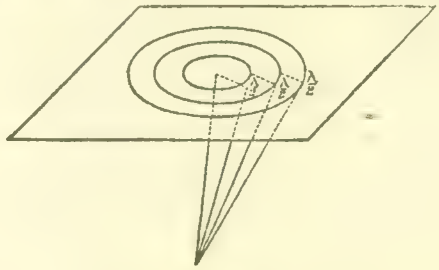


FIG. 7.

effect of the central circle is left uncompensated. But the distance of the edge of this circle is half a wave-length farther from the point than its center is, so that the resultant phase at the point will be behind that due to the center, but in front of that due to the edge, which effect would be half a period behind that arising from the center. Taking the mean between them, the resultant phase then at the point is a *quarter* of a period* behind what it would be if the center alone acted. Thus it was that the reflection from the *small* sheet of zinc differed from what I had expected it to be.

Experiment showing phase of secondary waves.—To experimentally test this, the small sheet of zinc was used as reflector in the Hertzian experiment of loops and nodes. Employing the circular resonator, the position of interference was found to have shifted out from 17 to over 24 centimeters, which nearly corresponds to an acceleration of phase of a quarter of a period, the wave going in all nearly a quarter of a wave-length farther, and nevertheless being still only half a period behind the phase on starting. The farthest out the loop could be is 25.5 centimeters: to obtain this would require an indefinitely small reflector. Of course, when the resonator was close in to the sheet, no change of phase was found to occur, the sheet being then practically infinite.

Another interesting observation was made. A *long* sheet of zinc, 30 centimeters wide, was found to act similarly to the sheet 30 centimeters square, provided it was placed with its breadth parallel to the electric displacement. When thus placed at 24 centimeters from the circular "resonator," there was interference, but on rotating the reflector so as its length was parallel to the electric displacement, sparking occurred, and now the "resonator" had to be brought back to 17 centimeters in order to again obtain interference. This experi-

* That it aided the back rather than the front was probably due to their phase not being an exact period or half period different from each other.

ment is interesting in connection with the electro-magnetic way of looking at the acceleration of phase as being due to the accumulations of electricity on the edges of the reflector, which is the same as the reason why it is necessary to use *long* cylindrical mirrors, as was pointed out by Professor Hertz in a letter last February to Professor Fitzgerald. This experiment is really the same as Stokes's *experimentum crucis*, as Professor Fitzgerald points out.

If instead of using the whole primary wave in the former experiment, it be passed through a screen with a hole in it (either square or a long slit at right angles to the electric displacement), the position of interference, as might be anticipated, was not shifted out as much as before. In the rough experiment made, it was found to occur at about 19 centimeters from the screen.

It was now thought well to repeat the determination of the index of refraction with a larger wall and metallic reflector than had been used before, as this change of phase might have affected the former results. But it was found that it had not done so to a sensible extent. However, the result of these new experiments was finally to give for paraffin, $\mu = 1.75$, and at the same time it was found that the wave-length given by the "vibrator" was 68 and not 66 centimeters, as had been assumed.

Two new knobs for the "vibrator" had been made, and the fact had been overlooked that they were slightly larger than the old ones, which gave a wave-length of 66 centimeters. These new knobs were electroplated with gold, and were a great saving of trouble, as they could be cleaned by merely rubbing with paper; apparently, the gold carried across by the sparking (in the form of a black powder) coming off,—but some may have re-burnished on. It was a curious thing that if the knobs were left uncleaned over night, the next morning it was very hard to get the black off,—some molecular change probably occurring.

If the value of μ thus found be not in some way due to the paraffin being in separate blocks, it would show a remarkable anomalous dispersion for paraffin near these curiously slow vibrations, and as suggested by Professor Fitzgerald, may be connected with the vibration periods of atoms in the molecule, as it can hardly be connected with the vibrations in the atoms themselves. It might be interesting to investigate whether these slow vibrations could cause dissociation, and thus lead to a photographic method of observing them. It may also be allied with ordinary electrolysis by very long period currents, as is also suggested by Professor Fitzgerald.

Assuming $\mu = 1.75$,* and $\lambda = 68$ centimeters, the thicknesses of the walls in the "Newton's ring" experiment, as above described, were wrong. However, it was found more convenient to alter the angle of incidence to

*This value agrees with polarization experiments. No reflection was obtained at its corresponding angle, while at $\tan^{-1} 1.51$ some sparks were occasionally seen.

suit the walls than to change the thickness of the walls. Thus, the mirrors were put at 25°, which is the proper angle with the above data for 10 centimeter and 20 centimeter walls. On now repeating the experiment, better results were obtained than I should have anticipated. When the wall was 10 centimeters thick, continuous sparking was easily obtained, but when 20 centimeters thick, it was only after much adjustment and patience that perhaps one slight spark could be obtained. This was quite sufficient, considering the nature of the wall, for it was only built up of plates, which afforded internal reflections, weakening the transmitted rays, and also since it requires the sum of the effect arising from the multiple reflections back and forward inside the wall to completely interfere with the front, and some of these are lost at the edge of the beam.

ON THE CONVERSION OF ELECTRIC OSCILLATIONS INTO CONTINUOUS CURRENTS BY MEANS OF A VACUUM VALVE

J[ohn] A[mbrose] Fleming

"On the Conversion of Electric Oscillations into Continuous Currents by means of a Vacuum Valve." By J. A. FLEMING, M.A., D.Sc., F.R.S., Professor of Electrical Engineering in University College, London. Received January 24,—Read February 9, 1905.

An electric oscillation being an alternating current of very high frequency, cannot directly affect an ordinary movable coil or movable needle galvanometer.

Appliances generally used for detecting electric waves or electric oscillations are, therefore, in fact, alternating current instruments, and must depend for their action upon some property which is independent of the direction of the current, such as the heating effect or magnetizing force. The coherer used in Hertzian wave research is not metrical, since the action is merely catastrophic or accidental, and bears no very definite relation to the energy of the oscillation which starts it. Even the demagnetising action of electric oscillations, though more definite in operation than the contact action at loose joints, is far from being all that is required for quantitative research. It is obvious it would be an advantage if we could utilise the direct current mirror galvanometer for the detection and measurement of feeble electric oscillations. This can be done if we can discover a medium with perfect unilateral conductivity.

Some time ago, I considered the use of the aluminium-carbon electrolytic cell with this object. It is well known that a cell containing a plate of aluminium and carbon, immersed in some electrolyte which yields oxygen, such as dilute sulphuric acid or an aqueous solution of any caustic alkali, or salt yielding oxygen, has a unilateral conductivity within limits. An electric current under a certain electromotive force can pass through the cell from the carbon to the aluminium, but not in the reverse direction.

This action has been much studied and is the basis of many technical devices, such as the Nodon electric valve.

The electrochemical action by which this unilateral conductivity is produced involves, however, a time element, and after much experimenting I found that it did not operate with high frequency currents. My thoughts then turned to an old observation made by me in 1889, communicated to the Royal Society, amongst other facts, in a Paper in 1889, and also exhibited experimentally at the Royal Institution in 1890.* This was the discovery: that if a carbon filament electric

* See 'Roy. Soc. Proc.,' vol. 47, p. 122, 1890, "On Electric Discharge between Electrodes at different Temperatures in Air and High Vacua," by J. A. Fleming, communicated December 16, 1889; see also 'Proceedings of the Royal Institution,'

glow lamp contains a pair of carbon filaments or a single filament and a metallic plate sealed into the bulb, the vacuous space between possesses a unilateral conductivity of a particular kind when the carbon filament, or one of the two filaments, is made incandescent. I have quite lately returned to this matter, and have found that this unilateral conductivity exists even with alternating currents of high frequency and is independent of the frequency. Hence, in a suitable form, it seemed possible that such a device would provide us with a means of rectifying electric oscillations and making them measurable on an ordinary galvanometer. The following experiments were, therefore, tried:—

Into a glass bulb, made like an incandescent lamp, are sealed in the ordinary way two carbon filaments, or there may be many filaments. On the other hand, one carbon filament may be used and a platinum wire may be sealed into the bulb terminating in a plate or cylinder of platinum, aluminium or other metal surrounding the filament. It is preferable to use a metal plate carried on a platinum wire sealed into the glass bulb, the plate being bent into a cylinder which surrounds both the legs of the carbon loop. The diagrams in fig. 1 show various forms of the arrangement. Diagram *a* shows a bulb with a single carbon filament surrounded by a metal cylinder, *b* shows one with two carbon filaments, and *c* a carbon filament and two insulated metal plates. The ends of the carbon filament which is rendered incandescent are marked + and − and the terminal of the other electrode of the valve is marked *t*. The bulb must be highly exhausted to about the pressure usual in the case of carbon filament incandescent lamps, and the metal cylinder or plate must be freed from occluded air.

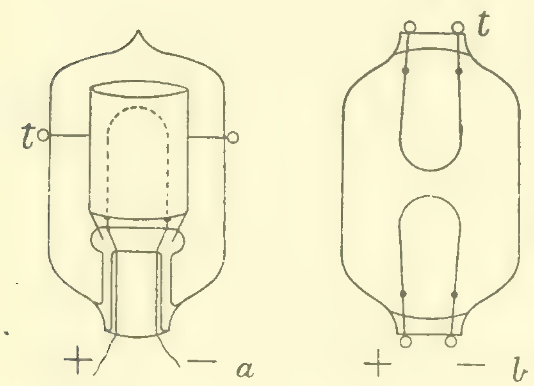
Suppose that we employ such a bulb containing one carbon filament surrounded by a metal cylinder (see *a*, fig. 1). The filament may be of any voltage, but I find it most convenient to employ filaments of such a length and section that they are brought to bright incandescence by an E.M.F. of 12 volts. The voltage and section of the filament should be so arranged that the temperature of the filament corresponds with an "efficiency," as a lamp-maker would say, of 2·75 or 3 watts per candle. The filament is conveniently brought to incandescence by a small insulated battery of secondary cells. A circuit is then completed through the vacuous space in the bulb between the cylinder and the filament by another wire which joins the external terminal *t* of the metal cylinder and that terminal of the carbon filament which is in connection with the negative pole of the heating battery. In this last circuit is placed a sensitive mirror galvanometer of the movable needle or movable coil type, and also a coil which may

vol. 13, Part LXXXIV, p. 45, Friday evening discourse on February 14, 1890, "Problems on the Physics of an Electric Lamp," when this unilateral conductivity was experimentally shown.

be the secondary circuit of an air core transformer in which electric oscillations are set up. As is now well known, the vacuous space in the bulb permits negative electricity to move in it from the hot filament or cathode through the vacuous space to the cylinder or anode and back through the galvanometer and coil, but not in the reverse direction, as long as the cylinder is cool and the carbon filament not at a temperature much above the melting point of platinum. To illustrate the action of the bulb as an electrical valve, the following experiments can be shown:—

Electric oscillations are set up in a metal wire circuit by the discharge of a Leyden jar, as usual. This circuit takes the form of a thick wire of one or more turns, bent into the form of a circle or square. Some distance from this, we place another wire, of several, say eight

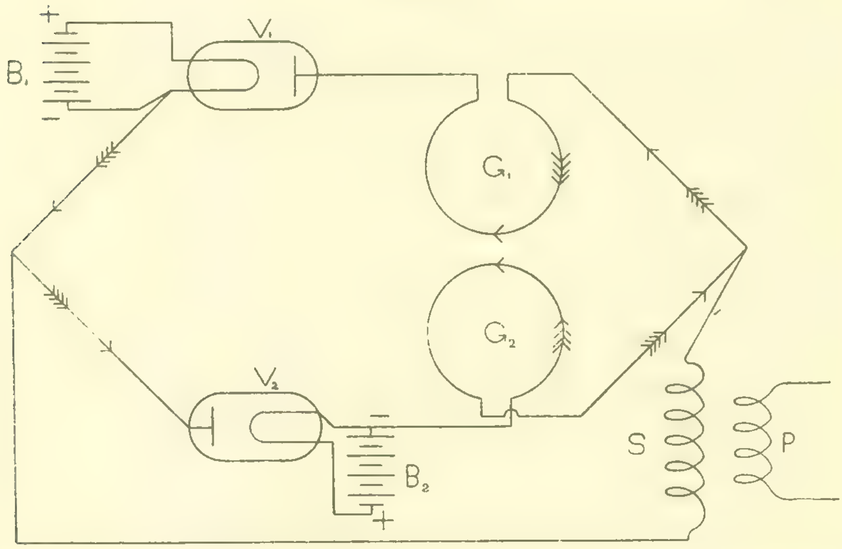
FIG. 1.



or ten turns, also bent into the form of a circle, and connect this last wire into the circuit of a galvanometer and vacuum bulb made as described, so that it is a circuit having unilateral conductivity. On exciting the oscillations in the primary circuit by an induction coil we have an alternating high frequency magnetic field produced, which affects the secondary circuit at a distance. The oscillations in this last are, however, able to flow only in one direction. Hence, the galvanometer is acted upon by a series of intermittent but unidirectional electromotive forces, and its needle or coil deflects. Since the field is a high frequency field, we can show the screening effect of a sheet of tin foil or silver paper in a very simple and effective manner by the effect it produces in cutting down the galvanometer deflection when the metal sheet is interposed between the primary secondary circuits. Also, if we move the secondary coil away from the primary coil or turn the two coils with their planes at right angles to one another, then the galvanometer deflection diminishes or falls to zero because the induction is decreased. Accordingly, we have in this vacuum valve and

associated mirror galvanometer a means of detecting feeble alternating electric currents or oscillations. Another method is to employ a differential galvanometer and two vacuum valves. These must then be arranged, as shown in fig. 2, one circuit G_1 of the differential galvanometer is in series with one valve V_1 and the other circuit G_2 with the other valve V_2, but so joined up that currents flowing through the valves in opposite directions pass round the two galvanometer wires in the same direction as regards the needle and, therefore, their effects are added together on the galvanometer needle. Each valve must then have its own separate insulated battery to ignite the filament. Also, it is necessary that the connection with the oscillatory circuit must be made in both cases to the hot filament by that terminal which is in

Fig. 2.



connection with the negative pole of the local battery used to ignite the filament (see fig. 2).

This arrangement of a differential galvanometer and two valves transforms, of course, more of the alternating oscillation into direct current than when one valve alone is used. It provides us with a means of detecting electrical oscillations not merely in closed circuits but in open electrical circuits.

When so using it, it is necessary to associate with the oscillation valve and galvanometer an oscillation transformer for raising the voltage. The resistance of these valves, when in operation, may be anything from a few hundred ohms up to some megohms, depending on the state of incandescence of the filament and upon the electromotive force employed to drive the current through the vacuous space, as well as upon the size of the filament and the plate. This resistance

does not obey Ohm's law, but the current increases to a maximum and then slightly decreases as the voltage progressively increases. The form of oscillation transformer employed with the device is as follows: A small air-core induction coil has a primary circuit, which consists of 52 turns of gutta-percha covered wire, wound in a helical groove cut on an ebonite rod 0·5 inch in diameter and 6 inches in length. The primary circuit is made of a No. 20 or No. 22 S.W.G. copper wire. The secondary circuit consists of 36,000 turns of fine silk-covered wire, No. 36, wound in six coils, each having about 6000 turns, and all joined in series. This secondary circuit has one terminal connected to one common terminal of the galvanometer and the other to the common terminal of the two oscillation valves (see fig. 4). The primary coil of this oscillation transformer has one terminal connected to earth and the other to a long insulated rod which acts as an aerial or electric wave collector. To prevent the direct action of the transmitter upon the secondary coil by simple electromagnetic induction, it is best to wind the secondary coil in two equal parts in opposite directions and to wind the primary in a corresponding manner.

If an electric wave sent out from a similarly earthed transmitter falls upon the rod, then an electrical oscillation is set up in the receiving circuit and therefore in the primary coil of the oscillation transformer inserted in series with it. This oscillation is raised in voltage by the secondary coil of the transformer, and by reason of the unilateral conductivity of a vacuum valve, placed in series with the coil, one part of the oscillation, viz., the positive or the negative current, passes round the galvanometer coils and affects it.

If we employ a sensitive dead beat galvanometer of the type called by cable engineers a "Speaking Galvanometer," then intelligible signals can be sent by making small and larger deflections of the galvanometer corresponding to the dot and dash of the Morse alphabet; anyone who can "read mirror" can read off the signals as quickly as they can be sent on an ordinary short submarine cable with this arrangement.

The arrangement, although not as sensitive as a coherer or magnetic detector, is much more simple to use. Also it has one great advantage, viz., that it enables us to examine the behaviour of any particular form of oscillation producer. By means of it we can detect changes in the wave-making power or uniformity of operation of the transmitting arrangement, by the variation of the deflection of the galvanometer. Thus, for instance, if a spark-ball transmitter is being employed and the deflection of the galvanometer in association with the receiving aerial is steady, if we put the slightest touch of oil upon the spark-balls of the transmitter, their wave-making power is increased and the deflection of the galvanometer at once increases. Since the current through the galvanometer is the result of the groups of oscillations

which are created in the receiving circuit, and since in the ordinary transmitter these oscillation groups are separated by wide intervals of silence, it is obvious that we can increase the sensitiveness of the above described arrangement by employing a very rapid break or interruptor with the induction coil. If, for instance, we employ a Wehnelt break with the induction coil or a high speed mercury break or alternating current transformer, we get a far better result as indicated by the deflection of the galvanometer than when employing the ordinary low frequency spring or hammer break.

The point of scientific interest in connection with the device, however, is the question how far such unilateral conductivity as is possessed by the vacuous space is complete. The electrical properties of these vacuum valves have accordingly been studied.

A bulb containing a 12-volt carbon filament rendered brightly incandescent by a current of about 2·7 to 3·7 ampères was employed. The filament was surrounded by an aluminium cylinder. The length of the carbon filament was 4·5 cm., its diameter 0·5 mm., and surface 70 square mm.

The aluminium cylinder had a diameter of 2 cms., a height of 2 cms., and a surface of 12·5 square cms. The filament was shaped like a horse-shoe, the distance between the legs being 5 mm. This filament was rendered incandescent to various degrees by applying to its terminals 8, 9, 10, and 11 volts respectively. Another insulated battery of secondary cells was employed to send a current through the vacuous space from the cylinder to the filament, connection being made with the negative terminal of the latter. The current through the vacuous space and the potential difference of the cylinder and negative end of the hot carbon filament were measured by a potentiometer. The effective resistance of the vacuous space is then taken to be the ratio of the so observed potential difference (valve P.D.) to the current (valve current) through the vacuum.

The following table records the observations. The column headed P.D. gives the potential difference between the hot filament and the cylinder, that headed A gives the current through the vacuous space in milliampères, that headed R the resistance of the space in ohms, and that headed $K10^5$ is 100,000 times the conductivity.

The result is to show that the vacuous space does not possess a constant resistance, but its conductivity increases rapidly up to a maximum and then decreases as the valve potential difference progressively increases. If we plot the current values as ordinates and potential difference of the valve electrodes as abscissæ, we find that the current curve quickly rises to a maximum value and then falls again slightly as the potential difference increases steadily. The conductivity curve also rises to a maximum and then decreases (see fig. 3).

The facts so exhibited are well-known characteristics of gaseous

Table I.—Variation of Current through, and Conductivity of, a Vacuum Valve with varying Electromotive Force, the Electrodes being an Incandescent Carbon Cathode and Cool Aluminium Anode.

Carbon filament at 11 volts, 3·77 amp., 41·47 watts.				Carbon filament at 10 volts, 3·44 amps., 34·43 watts.			
Vacuum Space.				*Vacuum Space.*			
P.D.	A.	R.	K10⁵.	P.D.	A.	R.	K10⁵.
0·6	0·024	25,000	4·0	0·7	0·014	50,000	2·0
5·4	0·264	20,550	4·86	2·8	0·073	38,360	2·6
8·8	0·480	18,330	5·45	8·2	0·392	20,920	4·76
18·2	3·880	4,691	21·4	12·8	0·824	15,530	6·56
22·9	26·790	855	118·1	16·2	1·739	9,316	10·70
29·1	28·02	1,038	96·1	20·1	5·352	3,756	26·6
37·1	28·426	1,305	76·6	23·3	9·68	2,407	41·4
49·0	26·50	1,719	58·0	35·9	10·037	3,577	28·0
70·2	26·87	2,613	38·3	49·7	9·794	5,075	20·0
100·0	24·36	4,105	25·0	71·6	8·920	8,027	12·5
				100·08	8·331	12,010	8·32

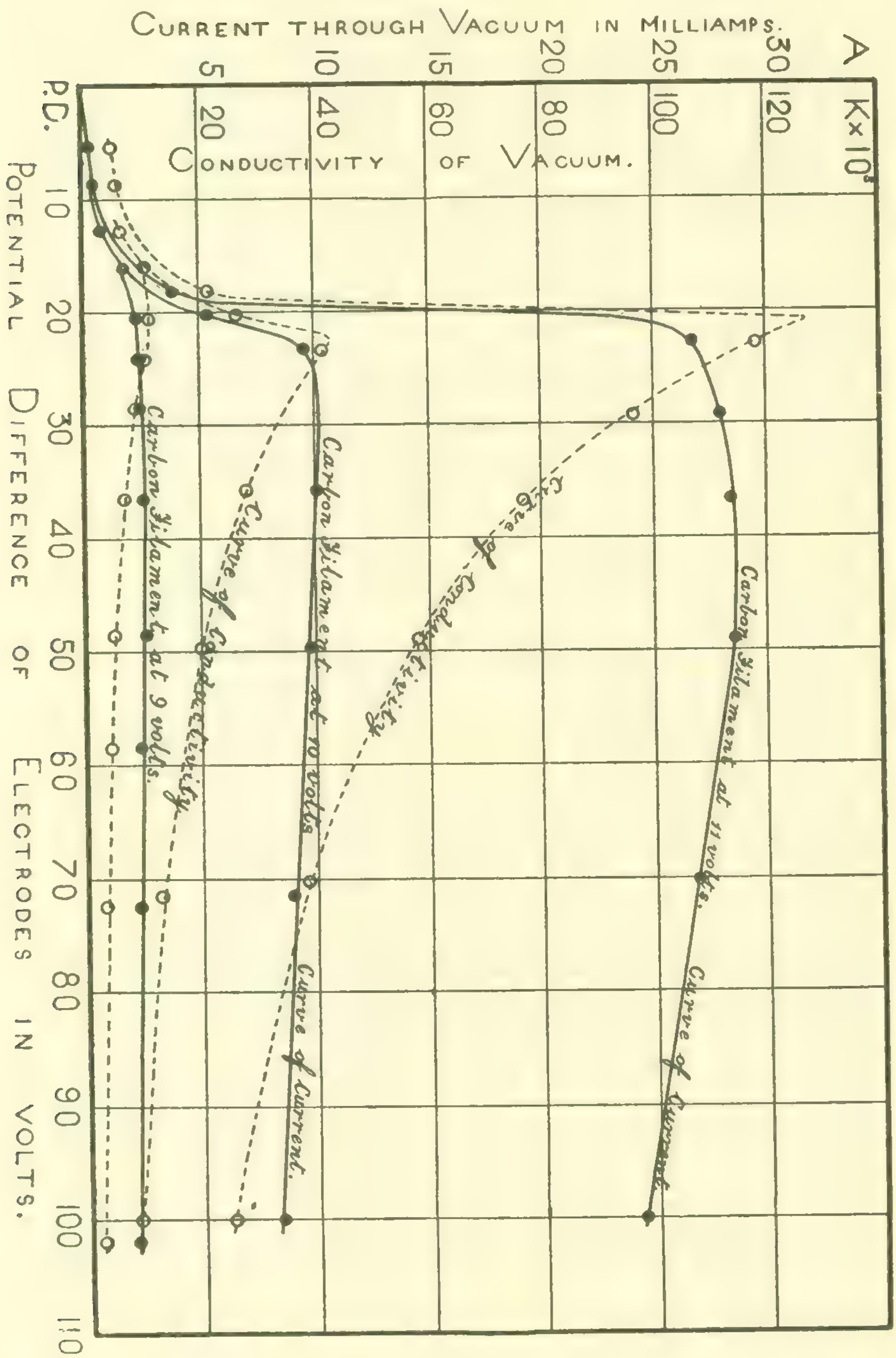
Carbon filament at 9 volts, 3·112 amps., 28·0 watts.							
Vacuum Space.							
P.D.	A.	R.	K10⁵.	P.D.	A.	R.	K10⁵.
0·5	0·005	100,000	1·0	24·2	2·389	10,130	10·0
2·5	0·049	50,020	2·0	28·2	2·437	11,650	8·6
5·2	0·128	40,625	2·46	36·6	2·508	14,590	6·86
8·3	0·324	25,620	4·0	48·6	2·535	19,170	5·0
8·8	0·361	24,380	4·1	58·5	2·374	24,640	4·0
12·6	0·70	17,970	5·5	72·5	2·253	32,180	3·0
16·4	1·735	9,452	10·5	102·0	2·067	49,350	2·0
20·4	2·351	8,677	11·2				

conduction in rarified gases.* It may be noted that there is in these current-voltage and voltage-conduction curves a general resemblance to the magnetisation and permeability curves of iron.

To examine further the nature of this conduction, the following experiments were made. If a vacuum bulb, as described, is joined up in series with a galvanometer and an electrodynamometer and an alternating electromotive force applied to the circuit, the two instruments will both be affected. The galvanometer is, however, affected only by

* See J. J. Thomson, 'Conduction of Electricity through Gases,' Chap. VIII.

Fig. 3.



the resultant flux of electricity in one direction. It measures the unidirectional current. The dynamometer is affected by the bilateral flux of electricity and it measures the total or alternating current. If, therefore, the vacuous space is totally non-conducting in one direction,

one half of the alternating current will be cut out. The galvanometer will read the true mean (T.M.) value of the remanent unidirectional current, and the dynamometer will read the root-mean-square (R.M.S.) value. If the conductivity in one direction is not zero, then the galvanometer will read the T.M. value of the difference of the positive and negative currents, but the dynamometer will read the R.M.S. value of their sum.*

In the last case, the current through the valve may be considered to be a continuous current superimposed upon an alternating current.

If we call I the maximum value of the nearly sinoidal current in one direction, and I′ the maximum in the opposite direction, then we may say that the dynamometer reading (D) expressed in true current value is equal to $g\,(\mathrm{I}+\mathrm{I}')$ where g is the *amplitude factor*, and also that the galvanometer reading (G) in true current value is equal to $g/f\,(\mathrm{I}-\mathrm{I}')$ where f is the *form factor* of the current.† Hence—

$$\frac{\mathrm{D}}{\mathrm{G}} = f\frac{\mathrm{I}+\mathrm{I}'}{\mathrm{I}-\mathrm{I}'}, \text{ or } \frac{\mathrm{D}/\mathrm{G}+f}{2f} = \frac{\mathrm{I}}{\mathrm{I}-\mathrm{I}'}.$$

The fraction $\dfrac{2f}{\mathrm{D}/\mathrm{G}+f}$, say β, expressed as a percentage may be called the *rectifying power* of the valve, for it expresses the percentage which the actual unilateral electric flow or continuous current through the valve is of that continuous current which would flow if the unilateral conductivity were perfect.

Perfect rectifying power, however, does not exist. There is not an infinite resistance to movement of negative electricity from the metal cylinder to the hot filament through the vacuum, although this resistance is immensely greater than that which opposes the movement of negative electricity in the opposite direction. This point was examined, as follows: A very sensitive electrodynamometer was skilfully constructed by my assistant, Mr. G. B. Dyke, the fixed coil having 2000 turns of No. 47 silk-covered copper wire and the movable coil 1000 turns. The suspension of the movable coil was by a fine flat phosphor-bronze wire at top and bottom. The deflection was observed by a mirror and scale.

* If i is the instantaneous value of a periodically varying current with maximum value I and periodic time T, then the root-mean-square value (R.M.S. value) of i is defined to be $\left(\frac{1}{\mathrm{T}}\int_0^{\mathrm{T}} i^2dt\right)^{\frac{1}{2}}$ and the true mean value (T.M. value) of i is defined to be $\frac{2}{\mathrm{T}}\int_0^{\frac{1}{2}\mathrm{T}} idt$.

† The *form factor* f and *amplitude factor* g are the names given by the author (see 'Alternating Current Transformer,' J. A. Fleming, vol. 1, p. 585, 3rd edit.) to the ratio of the R.M.S. to the T.M. value of the ordinates of a single valued periodic curve, and to the ratio of the R.M.S. value of the ordinates to the maximum value during the period.

This dynamometer was placed in series with a shunted movable coil galvanometer of Holden-Pitkin pattern, and the two together placed in series with a variable section of an inductionless coil through which an alternating current was passing. A vacuum valve as above described was in series also with the galvanometer and dynamometer. The alternating current was derived from an alternator giving a nearly true sinoidal electromotive force. The form factor of the electromotive force curve of this alternator was determined and found to be 1 115, that for a true sine curve being 1·111.

The vacuum valve sifted out the alternating current flow and allowed the currents in one direction to pass, but nearly stopped those in the opposite direction. The indications of the electrodynamometer were proportional to the root-mean-square (R.M.S.) value of the sum of the two opposite currents, and that of the galvanometer to the true mean value (T.M.) of their difference. The galvanometer and dynamometer were both calibrated by a potentiometer by means of continuous current, and curves constructed to convert their scale readings to milliampères. Then with various alternating current electromotive forces, their readings were taken when in series with a vacuum valve and recorded in the following tables. The letter D denotes current in milliampères as read by the so calibrated dynamometer and G that read by the galvanometer. The ratio D/G is denoted by α, and the rectifying power, viz., $2f/\alpha+f$ by β.

The table shows that the value of α is not constant, but for each state of incandescence of the filament reaches a maximum which, however, does not greatly differ from the mean value for the range of currents used. If we set out the mean values of β in a curve (see fig. 4), in terms of the power expended in heating the carbon filament, we see that the rectification is less complete in proportion as the temperature of the carbon filament increases. This is probably due to the fact that as the filament gets hotter, it heats the enclosing cylinder to a higher temperature and enables negative electricity to escape from the latter.

Hence, I feel convinced that if the metal cylinder could be kept quite cool by water circulation the rectification would reach 100 per cent. or be complete.

An ideal and perfect rectifier for electric oscillations may, therefore, be found by enclosing a hot carbon filament and a perfectly cold metal anode in a very perfect vacuum. With a bulb such as that used for the above experiments all we can say is that the current passed through the vacuum is from 80 to 90 per cent. continuous, 100 per cent. implying that the vacuum is perfectly non-conducting in one direction and permits the flow of negative electricity only from the hot to the cold electrode. The necessity for keeping the cathode cold is shown by the following experiment :—An alternating-current arc was

Table II.—Ratio of Electrodynamometer (D) to Galvanometer (G) Readings in Milliampères. Form Factor of E.M.F. Curve = $1{\cdot}115 = f$.

Carbon filament at 11 volts, 3·77 amps., 41·7 watts.

D.	G.	$D/G = a$.	$2f/a + f = \beta$.	
0·85	0·57	1·49	0·86	Mean = 0·82.
1·33	0·85	1·56	0·83	
1·87	1·16	1·61	0·82	
2·30	1·40	1·64	0·81	
3·20	1·88	1·73	0·78	
3·52	2·10	1·68	0·80	
4·54	2·81	1·62	0·82	

Carbon filament at 10 volts, 3·44 amps., 34·43 watts.

D.	G.	$D/G = a$.	$2f/a + f = \beta$.	
0·50	0·34	1·47	0·86	Mean = 0·83.
1·34	0·86	1·56	0·83	
2·28	1·48	1·54	0·84	
2·72	1·68	1·62	0·82	
2·78	1·71	1·63	0·81	
3·02	1·87	1·62	0·82	
3·53	2·17	1·63	0·81	
4·30	2·92	1·47	0·86	
4·25	2·88	1·48	0·86	

Carbon filament at 9 volts, 3·112 amps., 28·0 watts.

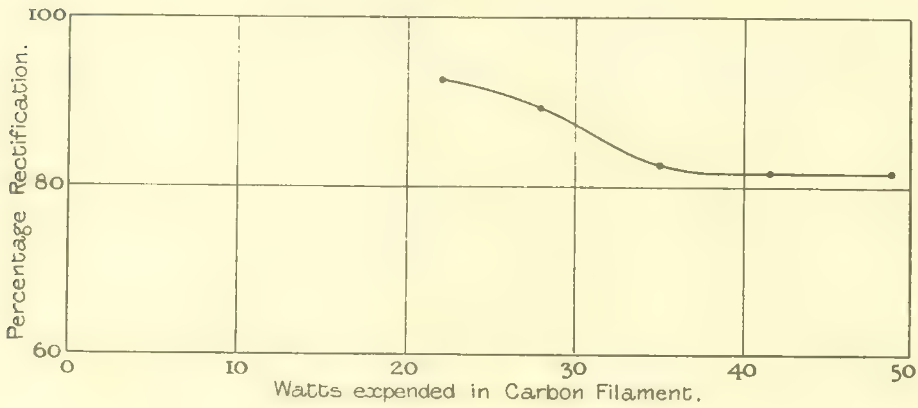
D.	G.	$D/G = a$.	$2f/a + f = \beta$.	
0·40	0·31	1·29	0·93	Mean = 0·89.
0·73	0·50	1·46	0·87	
1·28	0·83	1·54	0·84	
1·65	1·15	1·43	0·88	
1·82	1·26	1·44	0·87	
1·78	1·26	1·41	0·88	
1·93	1·35	1·43	0·88	
1·94	1·41	1·38	0·89	
1·87	1·41	1·38	0·91	
1·83	1·39	1·32	0·92	
1·73	1·37	1·26	0·94	

formed between carbon rods, and an iron rod was placed so that its end dipped into the arc. An ammeter was connected in between either carbon and the iron rod, and indicated a continuous current of negative electricity flowing through the ammeter from the iron rod to the carbon pole. This current was, however, greatly increased by making the iron rod of a piece of iron pipe closed at the end and

kept cool by a jet of water playing in the interior. In this manner I have been able to draw off a continuous current of 3 or 4 ampères from an alternating-current arc using 15 alternating-current ampères.

Returning, then, to the vacuum valve, we may note that the curves in fig. 3 show that the vacuous space possesses a maximum conductivity corresponding to a potential difference of about 20 volts between the electrodes, for the particular valve used. The interpretation of this fact may, perhaps, be as follows:—In the incandescent carbon there is a continual production of electrons or negative ions by atomic dissociation. Corresponding to every temperature there is a certain electronic tension or percentage of free electrons. If the carbon is

Fig. 4.



made the negative electrode in a high vacuum these negative ions are expelled from it, but they cannot be expelled at a greater rate than they are produced. Therefore, there is a maximum value for the outgoing current and a maximum value for the ratio of current to electromotive force, that is for the conductivity.

This fact, therefore, fixes a limit to the utility of the device. The current through the vacuous space is, to a very large extent, independent of the electromotive force creating it, and is at no stage proportional to it, or at least only within a narrow range of electromotive force near to the maximum conductivity.

Whilst, therefore, the device is useful as a simple means of detecting electric oscillations, it has not that uniformity of conductivity which would make it useful as a strictly metrical device for measuring them. It can, however, perform the useful service of showing us how far any device for producing electric oscillations or electric waves produces a uniform or very irregular train of electric oscillations, and what changes conduce to an improvement or reduction in the efficiency of the transmitting device.

THE AUDION
A NEW RECEIVER FOR WIRELESS TELEGRAPHY

Lee de Forest

A paper to be presented at the 210th Meeting of the American Institute of Electrical Engineers, New York, October 20th, 1906.

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THE AUDION.*

A New Receiver for Wireless Telegraphy.

BY LEE DE FOREST.

The story of the development of a device of a distinctively new order, from its first inception to its practical reality, adds a human interest to its description which is perhaps too often lacking among scientific records. In 1900 when I was beginning experiments on the electrolytic responder, it was my good fortune to have to work upon it at night in my own room, at a table beneath a solitary gas-burner with Welsbach mantel. My source of hertzian waves was the discharge of a small induction-coil placed in an opposite corner and set into operation by a key closed by pulling a string.

One night I noticed to my surprise a decided diminution in the light from the incandescent mantel whenever the coil was sparking. The constant recurrence of this effect induced me to investigate. By proper adjustment of the inflow of gas and air to the burner, an almost complete extinction of its light was obtained during the sparking of the coil. Another adjustment even allowed an increase of the light above normal For several days I was elated over the tremendously sensitive and altogether novel type of hertzian-wave responder thus accidentally discovered. But alas for the over-sanguine spirits of the young investigator! When I thrust my induction coil into a closet and closed the wooden door, thus shutting off the sound of its vibrator and spark, my gas-light ceased to fluctuate.

*For its name, Audion, a title as beautiful as it is appropriate, I am indebted to my assistant, Mr. C. D. Babcock, who has been of utmost service to me in the development of this device almost from its inception.

I found I had merely discovered an extremely responsive form of the sensitive gas-flame, and that a bunch of jingling keys, or a smart clapping of the hands were almost as efficient generators of these hertzian waves as was my induction coil. To hopes unrealized this was indeed the " Light that Failed."

But the few days of illusion had set me thinking. Here in the flame around this incandescent mantel was matter in a most mobile, tenuous state, extremely sensitive to sound and heat vibrations, infinitely more delicate than any arrangement of solid or liquid particles. Why should it not then in some phase or fashion respond to the hertzian vibrations also?

Unable to dislodge this conviction from my mind, I began later to search for the genuine response to electric vibrations in the gas-flame. I found the conductivity of the incandescent mantel surprisingly small however for any voltages which would be practical in a wireless receiver.

By soaking the mantel in a potassium or sodium solution and drying, I was finally able to pass a small current from a dozen dry cells through the flame surrounding it, using two platinum electrodes with a telephone receiver in circuit, and get a faint response to the genuine hertzian wave. The discovery that the effect predicted was actually present was intensely gratifying.

Experiments followed with the bunsen-burner and other forms of flame. In the coal-gas flame the exterior luminous portion is positively electrified, the interior negatively. To render these flames sufficiently conducting, salts of the alkali metals were introduced. Of these the caesium, potassium, and sodium salts are the most conducting, and in the order named. These salts were either injected into the flames as solution, or preferably put in a little platinum cup held in the luminous part of the flame and made the cathode of the telephone circuit. A platinum wire or disk held about 2 mm. above this cup acted as anode. The antenna and earth connection, or the two terminals of the oscillating receiving circuit, were connected to these platinum electrodes. An electromotive force of 6 to 18 volts, supplied by a battery of dry cells was sufficient to give a current of several milliamperes through the colored flame.

This early form of Audion, the flame receiver, was remarkably sensitive to weak high-frequency oscillations. The sound heard in the telephone was an exact reproduction of that of the transmitter spark, in pitch, variation of intensity, etc.

It was observed that the increase of current with electromotive force did not follow Ohm's law; a saturation value of the current was observed. Wilson has found that the maximum current which a salt vapor in a flame can carry is equal to

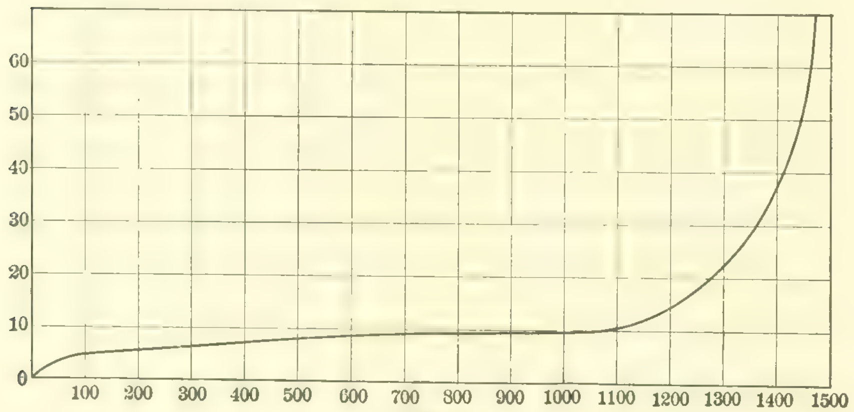

Fig. 1

the current which if passed through an aqueous solution of that salt would electrolyze the same quantity of the salt as was imparted during the same unit of time to the heated gas.

Beyond this saturation value the current will not rise until

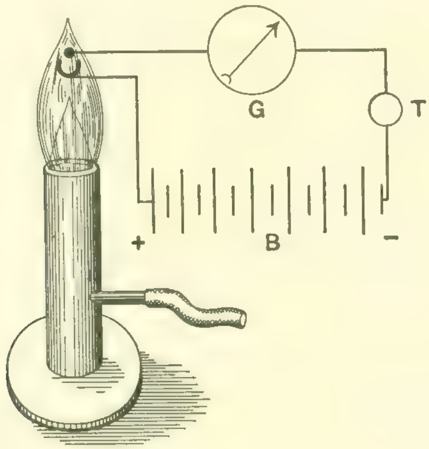

Fig. 2.

the electromotive force is great enough to enable the field itself to ionize the gas; that is, until the velocity imparted to the negative ions by the field is sufficient to enable them to separate the gas molecules with which they collide into positive and negative ions

The conduction through flames under the conditions I am describing is due chiefly to the negative ions generated, and these are chiefly in the vicinity of the metallic cathode. It is necessary that the alkali vapor comes in contact with the glowing metal. The increase of conductivity of a flame by the addition of a salt may amount to several hundred per cent., and is due not to the presence of the metallic atoms in the flame itself, but to the increase in ionization produced by the salt at the electrodes, notably the cathode.

The velocity of the negative ions in flames at atmospheric pressure increases rapidly with the temperature. Thus at 2000° cent. their velocity is approximately 40 times that at 1000° cent. At 1000° cent. the ratio of velocity of negative ions to positive ions is calculated as $\frac{26}{7}$. At 2000° cent. this negative ion velocity in flames is about 1000 $\frac{\text{cm}}{\text{sec}}$ for a potential gradient of one volt per cm.

Now suppose the average velocity of a negative corpuscle to be proportional to the electric force; this velocity, for a potential drop of 10 volts between the electrodes as I use them, is of the order required to traverse the distance between the incandescent body and the platinum anode during the time of one half the wave period of the electrical oscillations ordinarily used in wireless telegraphy.

I shall return later to the bearing which this fact has upon a suggested explanation of the effect of the hertzian oscillations upon the gas receiver.

On account of the ionization of the gas near the incandescent metal, and the greater velocity of the negative over the positive ions, it is to be expected that even if no external electromotive force be applied to the electrodes, and one of these be relatively cold, a current will pass along a wire connecting the two electrodes, whose direction is negatively from the hotter to the cooler body in the flame. In other words the colder body will be the anode, positively charged.

Now if the hertzian oscillations traverse the hot gas, the momentary potentials thereby impressed upon the moving ions will conceivably interfere with their motions, or with the rates of recombination between the positive and negative ions, and thus effect the current flowing through the wire. A telephone

connected between the electrodes indicates that changes of a surprising amount in the momentary potential difference, or flux, across the electrodes are effected by the high frequency oscillations, even when no external battery is applied.

When a battery of from 6 to 20 dry cells is connected across the two electrodes, the positive terminal to the cooler electrode, the potential current curve for the conductivity of the gas is at first approximately a straight oblique line, the current through the flame increasing with the electromotive force.

Soon however this proportionality of current and voltage ceases, and a stage of saturation is reached where there is no appreciable increase of current with increase of voltage. But when the potential difference is raised sufficiently to ionize the gas, a stage is reached where the current increase is far more rapid than that of potential difference. This last potential gradient depends upon the pressure of the gas; it is directly proportional to the pressure. This is given by Thomson as about 30,000 volts per cm. for atmospheric pressure; but with incandescent gases in an enclosed vessel at one mm. pressure a gradient of 40 volts per cm. is sometimes sufficient to produce this critical stage.

In the case of the flame the distances between the electrodes figures very little in the amount of current flowing, the potential drop, or the sensitiveness to hertzian oscillations, because most of the ionization at low voltages takes place at the electrodes.

The size and shape of the electrodes are of small moment. I prefer a trough anode 1 cm. long by 2 mm. wide, holding the potassium salt, as cathode, and a small platinum wire parallel thereto and held 2 to 10 mm. above it as anode.

The trough electrode should preferably be at the upper tip of the oxidizing flame at its junction with the reducing flame. When this is made negative the current is saturated with a comparatively small potential difference. The gas-burner itself may be used as one electrode. The flame must be steady and kept rich in salt. The current of up-rushing flame makes a rumbling noise in the telephone, which may interfere with the detection of faint signals. This rumbling sound increases with too great applied potentials.

The temperature, especially of the electrodes, is an important factor. At red heat these give off positive corpuscles; at white heat both positive and negative appear, the latter predominat-

ing. The electrode containing the salt should always be incandescent, so that the excess of negative ions given off and streaming towards the other electrode will increase, rather than diminish the current due to the flame itself. The extreme sensitiveness of the flame when ionized to thermal variations is illustrated by the fact that a distinct response is heard in the telephone receiver when the mere tip of a cold pin is suddenly introduced into the flame. The sudden introduction of a cold body into the active part of the flame always reduces the response. The salt is best placed in, or on, one of the electrodes rather than held in the flame in an independent receptacle, or injected into the gas.

The applied electromotive force is a determining factor in the sensitiveness of this receiver. The response seems greatest where the potential current curve is passing from the oblique to the horizontal portion, where the saturation value is about to be reached Under these conditions the sensitiveness of the flame Audion is of the same order as that of the electrolytic receiver using a glass-jacketed electrode. The flame is not most sensitive when the flux is greatest. There is a close relation between the degree of heat and the critical impressed voltage

Considerable difficulty was found in getting an absolutely steady flame, even when protected by a chimney, as the slightest air current will deflect the sensitive portion from the electrodes, altering the sensitiveness of response.

I next sought the phenomenon in the hot conducting gases of the electric arc. If a wire be connected to the positive carbon of the arc and lead through a telephone to a third electrode, platinum or carbon, which is inserted into the border of the arc, a considerable current passes through the telephone. If these two electrodes are now connected to the terminals of the receiving oscillating circuit, the conduction of the leak current across the gas to the third electrode is sensibly affected by the arriving hertzian oscillations, if sufficiently intense. A local battery can also be inserted in series with the telephone, but the voltage drop across the arc is usually too great to require this.

Even when the arc is fed from a storage-battery and cored carbons used, the hissing and frying noises in the telephone (probably due to the oxidation of the terminal by the air) are generally too troublesome to allow a clear reading of weak signals with this form of Audion.

The principles involved in its operation are much the same as for the flame Audion. And although the intense ionization produced by the heat of the arc renders it extremely sensitive to slight local variations, its practical requirements make it less available as a wireless receiver.

Inasmuch as the gases ionize more readily at lower heats and are in their most mobile, delicate, and sensitive conditions

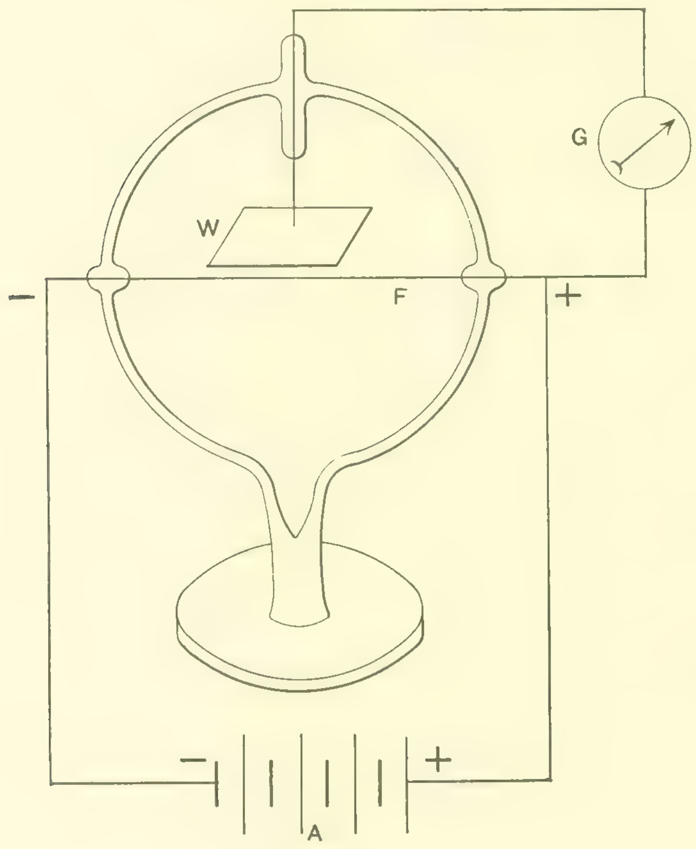

Fig. 3

in vacuum, it seemed to me certain, after experiments with the flame, that the attenuated and ionized gases around an incandescent filament would undergo very considerable changes when subjected to hertzian oscillations.

Elster and Geitel,* beginning in 1882 a systematic investigation of the ionization produced by incandescent metals, frequently employed an exhausted glass vessel containing an

*Elster and Geitel, Wied. Ann., xvi., 1882.

insulated platinum plate, stretched close to which passes a fine metallic filament brought to incandescence by an electric current.

Ordinarily at atmospheric pressures and red heats a positive charge was produced upon the plate, of the order of a few volts. This potential increases until the wire is at a yellow heat. As the wire gets hotter the potential decreases, until at a bright white heat the potential of the plate is very slight. Diminishing air pressure has but slight effect upon the plate potential until very high exhaustions are reached, when this potential begins to diminish and may even change sign, and as the exhaustion proceeds may reach a very large negative value. This pressure where the plate charge changes sign depends upon the temperature of the filament, being higher at higher temperatures.

Long-continued heating and expulsion of gas from the incandescent metal play a considerable part in the electrical phenomena. Long-continued incandescence favors the negative electrification of the plate. The presence of oxygen aids in the carrying off of a negative charge, thus producing negative electrification around the wire; hence the action of oxide of metal on filaments tends to increase the discharge of negative electricity. But oxygen also hastens the disintegration of the filament.

Gases which are disassociated by heat conduct on quite a different scale from those like air, hydrogen, or nitrogen. Examples of such are the vapors of iodine, bromine, chlorine, potassium, iodine, etc. These furnish a much larger supply of ions than the others. This dissociation occurs chiefly where the gas is in contact with the glowing electrodes. Of the metals, sodium and potassium have the highest conductivity under the above conditions, for the emission of negatively electrified corpuscles from sodium atoms occurs even at low temperatures; and I have used carbon filaments coated with a potassium compound. The conductivity of cold mercury vapor does not seem greater than that of air.

With hydrogen, the plate becomes negatively electrified even at atmospheric pressure; and when the filament is carbon instead of platinum the electrification on the plate is always negative. This means that the gas will discharge the plate if positively electrified; that is, a positive current will pass from the plate to the filament in the gas.

The electrification produced in the neighborhood of an incandescent wire is a complicated effect; it depends on the temperature and nature of the filament, and on the nature and pressure of the gas. It furthermore depends upon the electric and magnetic forces to which the vessel is subjected; and I have found that the shape and area of the plate or plates, the condition of its surface and edges, as well as its distance from the filament, are very important factors.

If the metal plate be connected by an outside wire to the positive terminal of the hot filament, a leak-current from the plate to the filament through the gas will be set up, as Elster and Geitel first found, passing mainly to that portion of the filament near its negative terminal. If the resistance of the lamp fila-

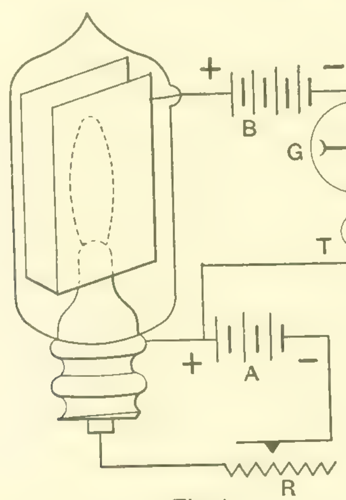

Fig. 4

ment and the lamp's voltage be high, a very considerable leak current may thus be set up.

A battery of from 3 to 18 dry cells is connected between the positive end of the filament and the platinum plate *w*, the latter being connected to the positive pole. The saturation current increases rapidly with the heating current through the filament, which also increases the velocity of the negative ions, as does also an increase in the applied electromotive force between plate and filament.

The rate of discharge of negative electricity from glowing carbon greatly exceeds that from platinum, while that from tantalum and other of the newer filaments, given the same heating current, surpasses the rate of discharge from carbon.

Thomson states the equation connecting the saturation current with the temperature as

$$\left(I = A\,\theta^{1/2} e^{-\frac{b}{\theta}}\right)$$

where θ is the absolute temperature, a and b are constants.

At 2000° cent. this rate of emission from a platinum wire in high vacuo amounts to 0.1 ampere per sq. cm. of hot surface. For carbon this current can equal several amperes per sq. cm. surface. In the Audion the flux current ordinarily ranges from 1 to 5 milliamperes.

The metal dust, or even vapor, from the incandescent filament may play a part in the phenomena but not a controlling one. Thomson has shown that the value of e/m for the carriers of electricity in the type of exhausted vessel described is the same as its value for the carriers of the negative electricity in the cathode rays, or in the discharge of negative electricity from metals illuminated by ultra-violet light. In fact in many ways the behavior of the Audion, notwithstanding the extremely low potentials used, is very similar to that of a cathode-ray tube; and in one or two small pea-lamps where the anode disk was close to the bend of the filament I have actually obtained, at only 22 volts, a blue-white beam of light playing between the filament cathode and the anode. Upon the approach of a powerful magnet this beam could be concentrated and deflected. A great increase in the current through the telephone marked the formation of this beam, and a violent hissing or squealing sound began when the magnet was approached.

The corpuscles at the filament are attracted by the metal of the filament, and to escape into the surrounding space they must be given sufficient kinetic energy to carry them through the surface layer where this attraction for the carriers is appreciable. Thus as the temperature of the filament increases, a larger number of the carriers can escape from the wire. But the saturation values of the flux current do not depend upon the velocity of the ions, but only upon the number of ions produced in unit time at the surface of the hot metal.

The source of ionization is confined to the gas immediately surrounding the filament. The velocity of the ion at any instant is dependent on its distance from the filament, because the temperature is not uniform between filament and plate. The ratio of the velocities of negative to positive ions varies

greatly with the temperature: thus they are given as 1000 to 62 at 2000°.

This fact explains why the positive conductivity of the gas in the vessel is almost entirely from the cold to the hot electrode in the gas, and not in the reverse direction; and why this unidirectional qaulity is more marked for higher temperatures of the cathode, the anode being kept cold.

In the form of Audion illustrated in Fig. 4, I employ two platinum wings parallel to the plane of the bowed filament and about 2 mm. on either side of it. These wings are soon coated with an iridescent deposit from the metal filament, especially at the portions opposite to the negative half of the filament. They become quite hot at this short distance, but not sufficiently hot to take part in the ionization of the gas.

When connected in the oscillation circuit as shown, properly attuned to the receiving electromagnetic impulse from the antenna, the Audion under proper adjustment of heating current and battery B potential is extremely sensitive, giving response in the receiving telephone several times as loud as any other form of wireless receiver when subjected to the same impulses. It is, however, less sensitive to atmospheric or static disturbances, which are strongly damped or a-periodic.

I find the device extremely closely tuned with the syntonizer, for its operation seems to be dependent upon the sum total of the energy received from the complete wave-train rather than upon the maximum first impulse of the train. In other words, while instantaneous as far as our senses or instruments can perceive, its action is sufficiently sluggish to be determined by the additive effect of the entire received electro-radiant energy through a short time-interval.

When the filament is first lighted, an appreciable interval, about one-quarter second, elapses before the full sensitiveness is established. Before the flux reaches a steady state there is a period during which the number of ions is steadily increasing. As result of the colliding of the initial ions with the gas molecules the number of ions and the current rapidly increase, until an equilibrium is finally attained.

The Audion, to a greater extent than any other responder, is self-tuned. I mean that by regulating the heating current, the potential between wing and filament, or the distance between these, the Audion can be made to a great extent selective *per se* to certain received impulses. And the determining factor

here is not merely the frequency of the electrical oscillation; the spark frequency, or factors determining the total amount of energy received during a very brief unit of time, determine to an extent the amount of its response. Thus with 12 volts across it, it may give a loud response to a transmitter *A*; and with 10 volts "bring in" another transmitter *B* to the almost complete exclusion of *A*, although *A* and *B* are of equal power and of approximately the same wave-length, but differing considerably in spark frequency. Similar discrimination can be produced by adjustments of the heat of the filament, which also governs the amount of flux through the gas.

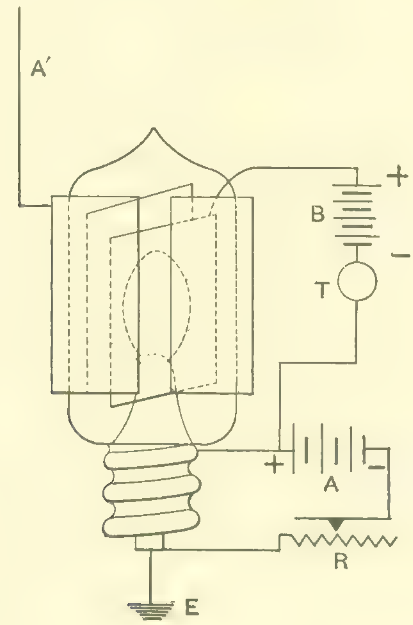

Fig. 5

This flux is generally reduced when the Audion is placed in a strong magnetic field, especially when the lines of force pass through the gas parallel to the plane of the wings, at right angles to the electric field. By this means also a tuning can be effected.

Again it is not necessary to connect the anode to a terminal of the oscillating circuit. One terminal may be attached to a metal sheath or ring surrounding the glass vessel, thus forming a condenser with the filament or the conducting gas within the tube. In this case the adjustment of the syntonizer is generally different from that required for the same oscilla-

tion frequency, when the interior wing is directly connected in the oscillation circuit. In this condenser arrangement also the sound heard in the telephone changes its quality to an extraordinary degree, being of a dull muffled nature rather than sharp and staccato. Signals of this quality are sometimes much more readily distinguished from the " static " disturbances which so frequently render wireless signals difficult to read. The operator has thus a ready means of changing the quality of the received signals to suit the conditions. This latter type of Audion is the one I have found most serviceable in practice.

The Audion may even be placed in the space between two

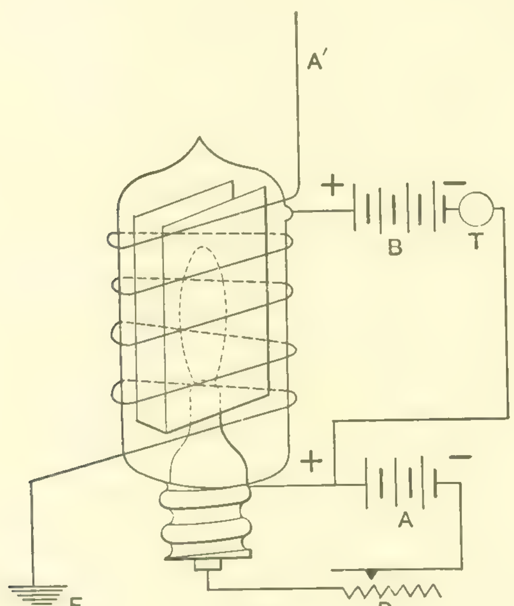

Fig. 6

plates of an air condenser in the oscillating circuit. A flat-walled type of tube is preferred for this arrangement. Again the electrical oscillation may be led through a coil of wire wound round the outside of the tube (Fig. 6), and not through the Audion at all, or through a flat coil brought up close to the tube, with its axis perpendicular to the filament. In this arrangement it is chiefly the electromagnetic component of the passing oscillation which affects the motion of the ions within the vessel. The ions are readily influenced by a magnetic field.

By shifting the syntonizer connections from the wings to

this helix, I have been able to cut out completely signals from a transmitting station so near as to baffle all attempts with the ordinary tuner methods, and to bring in other relatively faint signals.

The Audion has the further advantage of entire absence of adjustment in the receiver itself. It gives no evidence of fatigue under any conditions of use. Furthermore, it requires no protection from the violent impulses of the transmitter at its own station, whereas the sensitiveness of the electrolytic receiver is completely destroyed by one such violent impulse, unless its small electrode is protected by a shunting switch.

I have arrived as yet at no completely satisfactory theory as to the exact means by which the high-frequency oscillations affect so markedly the behavior of an ionized gas. Fleming points out that when the cold plate of the Elster-Geitel tube is connected to the positive end of the filament, and the two put in a high-frequency oscillation circuit, only the positive half of the oscillation can pass from the plate to the filament across the gas. He uses this principle to rectify the hertzian oscillations, and applies the unidirectional currents of the oscillations themselves to operate a sensitive galvanometer, or direct-current instrument, for quantitative measurements over very short distances.

When an independent external source of electromotive force is applied, in the manner I have described, the action becomes quite different. It then operates as a *relay* to the hertzian energy instead of merely rectifying this energy so that it can be used directly to give the sense signal.

The Audion therefore is tremendously more sensitive and available in practical wireless. A sensitive direct-current instrument in the *B* circuit shows a steady deflection varying not a whit, by increase or decrease, during the reception of strong "wireless" signals. An electrolytic receiver or "polariphone" under similar conditions would cause a great deviation in the deflection of a milliammeter, although the signals in the telephone with the electrolytic are not so loud as with the Audion.

I have connected two Audions in series in opposition in the oscillating circuit, each with its separate heating circuit and still heard the signals in the telephone connected to the second Audion equally well whether the wing in the first be connected to the wing or to the filament of the second.

When one of the tubes is unlighted, or if lighted its *B* circuit

is open, no high frequency impulses pass through it unless the wing and filament are very close together. When cold it acts merely as a condenser whose armatures are the wings and filament and whose capacity is extremely small.

I have laid considerable stress upon the potential gradient or " variation " layers which exist near the surface of the electrodes when the external applied electromotive force is considerable, for the reason that their existence serves to play a very important rôle in the response of the Audion to minute high-frequency oscillations.

If the velocity of negative ions is very large compared to that of the positive ions, the curve representing the distribution of electrical intensity between the two electrodes is represented by the following, which is typical.

When ions of both signs are present in the gas and when the electric field is so strong that most of the positive ions are driven from the anode and the negative ions from the cathode (the filament), we will have an excess of cations in front of the anode and of anions surrounding the cathode.

It is seen that the variation in potential lies chiefly in the thin layers of gas in front of the two electrodes. It is convenient to speak of these regions as the " variation " layers. As Thomson points out, in passing from the inside to the outside of the layer of ionized gas we have to pass across a layer of electricity. This will produce a discontinuity in the electrical intensity equal to 4π times the surface density of the electrification.

There may thus be a great difference between the electric intensity inside the layer and that just outside. The potential drop across the layer is proportional to the square of the current; the falls of potential at the positive and negative electrodes are proportional to the squares of velocities of the positive and negative ions; and the velocity of the ions is proportional to the electric force acting upon them.

These variation layers at the electrodes of the Audion make still more striking its similarity with the cathode-ray tube. In the cathode tube a sudden drop in potential called the " anode fall of potential " occurs quite close to the anode; and in the layer called the Crookes dark space, or cathode dark space, there is a still greater fall in negative potential. But the voltages here are enormously higher than those in the Audion. As the gas pressure in the cathode tube diminishes, the dark layer, or the cathode drop layer, becomes

broader. $D = \alpha + \beta\lambda$; that is, the width of the dark space is proportional to the mean free path of the molecules, beyond a certain distance α in front of the cathode. Schuster found that the thickness of the cathode drop layer increased slightly with the current passing through the gas; but Wehnelt found just the reverse. Both may be correct on different sides of some

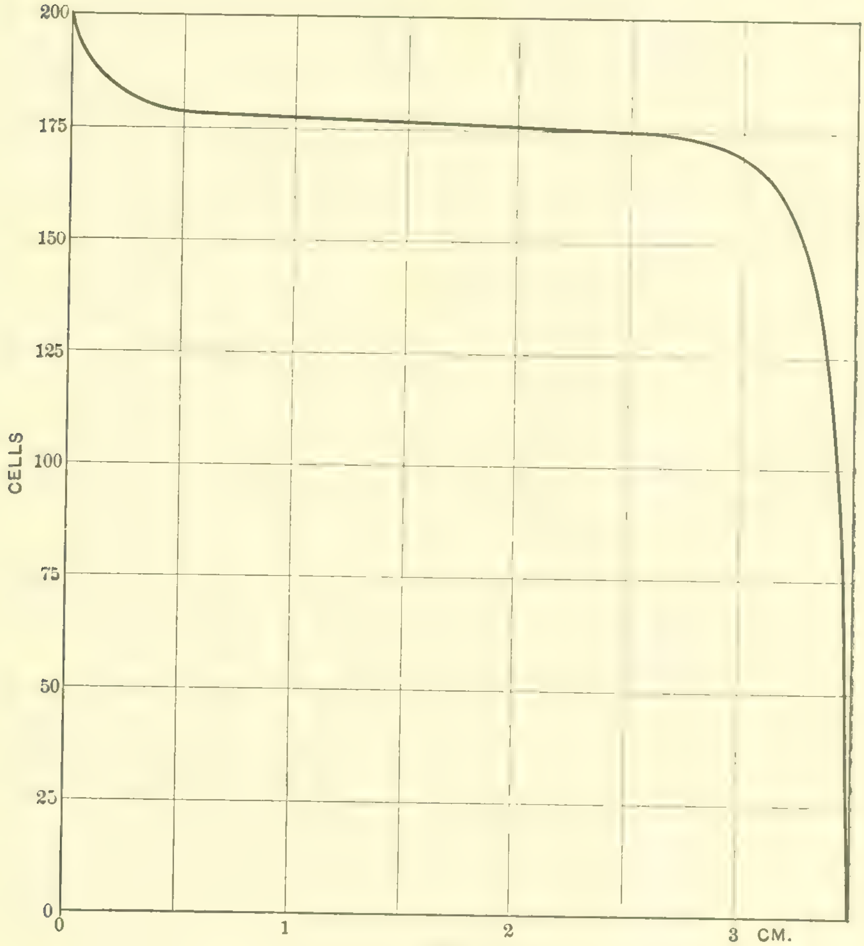

Fig. 7

particular value of the current for which the width of this space is a minimum. This is interesting in view of the fact that there is a certain current flux across the gas of the Audion for which the response of the hertzian oscillations is maximum; supposing this response is maximum when the width of the variation layer around the filament is minimum.

Within the cathode layer there exist only negative ions,

these being shot off from the cathode. Right outside of this, in the region called the "cathode glow" ionization of the gas from collisions with these negative ions begins, and the width of the cathode dark space is about the range of the "mean free path" of the ions.

If a similar state of affairs exists around the filament of the Audion, and if this mean free path of the cations coincides with the excursion of the corpuscles during one half the oscillation period of the impressed hertzian vibration, we might expect under these conditions a maximum effect of response to oscillation of the particular wave-frequency. Or a similar effect might be expected if the excursion in question is that of an ion from the cathode across the gas up to the layer surrounding the anode.

The extent to which the sensitiveness of the Audion is governed by a very slight change in the heating current, or in the potential drop across it, seems to lend plausibility to such an explanation. And it has been shown that in conducting flames at atmospheric pressure, a negative ion acting under a potential gradient of 10 volts per mm. would travel approximately 1 mm., or a commonly found distance between the electrodes in the Audion, in $\frac{1}{1,030,000}$ part of a second, which time-interval is of the order of one-half the wave period of some of the longer oscillations used in wireless telegraphy. For reduced gas pressures the natural excursion of the ion would be more rapidly accomplished, but its velocity can be governed within wide limits by regulating the applied electromotive force. When we send more current through the filament we increase the potential difference between filament and anode as well as increase the heat. Both changes act to increase the ionic velocity.

In Humstedt's experiments where a cathode-ray tube was exposed to high-frequency oscillations, the width of the cathode drop layer, or dark space, diminished as the frequency of the oscillations increased; as if there might be some connection between the period and the time involved in the immigration across. And many facts observed in connection with the Audion otherwise difficult to explain tempt one to suppose that here the degree of response is connected with the relation between the product of velocity of the ions by the distance between the electrodes, and the period or half period of the electrical oscillations received.

When the anode consists of two parallel plates instead of a cylinder there will be a maximum of positive electric density along their vertical edges. The more intense parts of the electric field will involve the larger number of ions, and on the anode these will generally be located at the vertical edges of the parallel plates, provided these are not too far from the filament.

With this type of anode a peculiar and sudden inflection point in the current-flux diagram, as the heating current is gradually increased or decreased, is noticed. The flux goes on increasing, then suddenly drops back to a lesser value; at the same time a click is heard in the telephone in the *B* circuit. Then as the

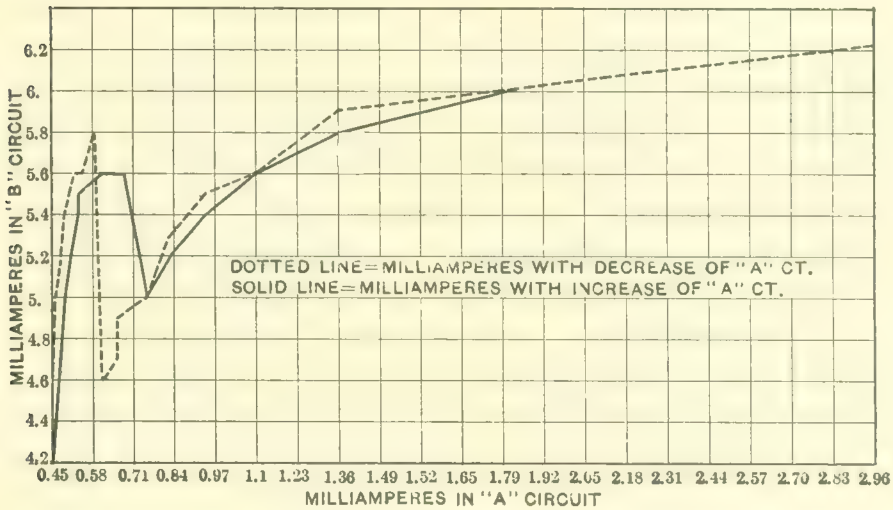

Fig. 8.

heating current is still further increased the *B* flux is again increased. These same cusp points in the curve are obtained if the *A* circuit be kept constant and the *B* voltage is increased instead.

Similarly, a click is heard when the flux current is being reduced from a higher value, only the location of the cusp on the curve of decreasing current is not coincident with but lags behind that observed when *B* is being increased. This second cusp point shows a sudden *increase* in the flux current, when the critical point is reached, to a value previously passed through. Naturally the sharpness of these cusp points can be smoothed out or quite obliterated by putting impedance in the *B* circuit in series with the telephone.

The diagram (Fig. 9) shows the relative magnitude of these sudden alterations in the flux current obtained with a certain sample Audion, and also the decided hysteresis effect, showing how the actual B current lags behind the increasing or decreasing electric field which produces it. This hysteresis effect

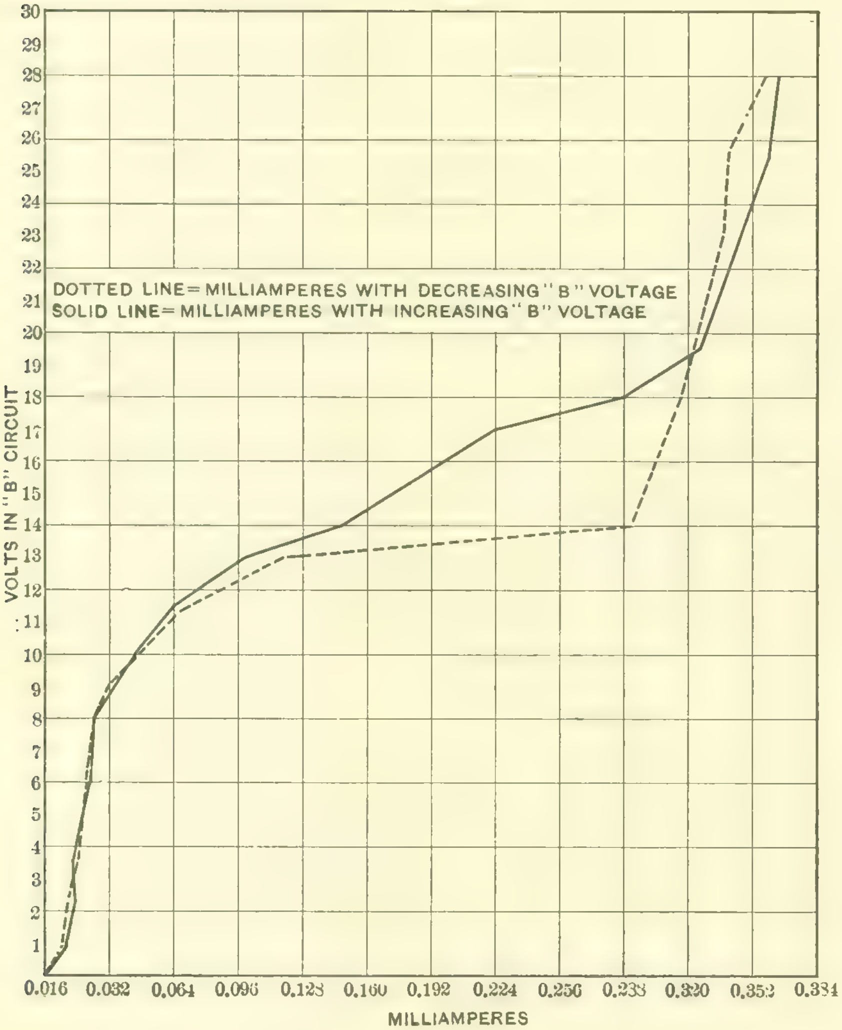

Fig. 9.

is very like that obtained when the molecular structure of iron is altered under a changing magnetic field. Doubtless it is here due to a reluctance of the ions to accommodate their paths and velocities to the impelling electric forces; and the area included between the two curves represents the work lost in accomplishing this conformation.

These hysteresis curves are always obtained even though the anode is in the form of a cylinder or flattened cylinder without the vertical edges; but the *reactive* cusp points in the curves are never obtained save with two plane anodes connected together.

Zeleny* has found a similar very curious hysteresis effect in the currents obtained from the ions from a platinum wire when heated and exposed to ultra-violet light. When the metal was cooling these currents were greater than those for the same temperature when the metal was being heated. In this case heating the wire produces some change in its surface, possibly in the amount of gas condensed thereon or absorbed by it, from which it recovers very slowly.

As B voltage is increasing and A current is increased and decreased, I find that the points at which the cusps occur on the increase and decrease A-B curves coincide more and more nearly and at the same time these cusps become less and less violent. The hysteresis effect is less pronounced as the B voltage is increased. As shown in the curves for a large B flux the two A-B curves for increasing and decreasing A current coincide almost exactly until B flux is reduced to a certain amount. They may again cross each other at a lower point of B flux, again diverge, and then coincide once more near their origin. These curves were all taken with Audions of the double-wing type, which feature may account for some of the very peculiar characteristics observed.

The filament is always at some part nearer to one wing than the other. Hence the B flux is chiefly concentrated on this wing or portion of wing, like a beam of cathode rays. We may suppose that as the B voltage is increased, as when more heating current is passed through the filament, the flux is increased and spreads out over this wing until a new sheaf or " ray " of ions, starting off from the filament from another part or in a new direction, suddenly leaves that wing and takes by preference a shorter path to the opposite wing. We would suppose that a new path thus taken would first be located on one of the vertical edges of the wings parallel to the filament.

This sudden diminishing of the intensity or density of the original beam of ions may be accompanied by a decrease in the velocity of propagation of the ions, and thus the resultant flux

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*Zeleny, Physical Review, Vol. XII, 1901.

be actually less than before. The reverse operation will occur when the *B* flux is being decreased from a high value.

When the anode consists of one wing only, no such reverse cusp-points, or reversals of the flux increment, have been obtained. With a single-plane anode however there is found a point at which the flux if increasing assumes a sudden increase in magnitude, representing an abrupt rise in the otherwise smooth flux-voltage curve; and the reverse when the current flux is being decreased.

These effects seem to relate to the increased values of the positive variation layers along the vertical edges of the anode which parallel the filament. The distribution of the charge upon the surface of the plate may be described as analagous to that of a thin film of liquid which coalesces and is heaped up along the edges, and from which, when the liquid is by any means drawn away, there is a sudden recession; the liquid, on account of the surface tension, letting go or taking hold of the edge all at once.

It is significant that just at a cusp point the sensitiveness of the Audion to the hertzian oscillations attains a marked maximum. Under the critical conditions then obtaining the slightest change in the applied electromotive force is accompanied by relatively great changes in the *B* flux.

In framing any theory of the action of electric oscillations in the Audion a variety of complex, contradictory phenomena are met with, exceedingly puzzling to explain. An example is the fact that a continuous-current instrument either in the *A* or the *B* circuit shows absolutely no change of deflection either of increase or decrease, when *B* is large and the Audion in its most sensitive condition. If only the positive halves of the oscillations pass from anode to filament these should increase the reading of a milliammeter in the *B* circuit during the passage of a long series of wave-trains of sufficient intensity. Or else the negative halves of these oscillations might be expected to diminish to a greater degree the positive charge on the anode, and result in a diminution of the *B* circuit. Or if both of these acted equally and oppositely no signal would be obtained at all, for the telephone diaphragm is utterly incapable of following such rapid increase and decrease in the *B* current, even if its impedance would allow these pulsations to pass through the circuit. Neither would the ear detect such vibrations.

If on the other hand the integrated effect of a complete

hertzian wave-train were either to increase or decrease the B flux, a long succession of such effects, all of which must be of the same sign, ought to cause a change in the needle's deflection, as when a long Morse dash is sent out from the transmitting station. We have no reason to suppose that one wave-train, the result of one spark, would produce a momentary decrease in the B flux, indicated by a click in the telephone, and that the next succeeding wave-train from the next spark would cause an opposite *increase* in the B flux, and another similar click in the telephone. Such action would of course explain why a loud sound in the telephone might not be accompanied by any change in the sluggish ammeter reading, similar to the case with the magnetic detector.

The following explanation of the phenomena which seems to account for many of the peculiarities of this paradox has been suggested. It should be remembered that if the negative half of the electric oscillation can not pass through the gas from cold anode to the filament the Audion electrodes during that half-period will act merely as the two armatures of a condenser. Even when close together, their mutual capacity, when the gas is cold, is exceedingly small, and only a very small positive charge can be held bound on the filament; or if there are sufficient free positive ions in the hot gap the complimentary positive charge will be held just on the outside of the "variation layer" at the anode.

The fall of potential across the variation layers at anode and cathode are proportonial to the squares of the velocities of the positive and negative ions; and the ionic velocities are proportional to the electric forces acting upon them. Supposing then that during the positive half of the electric oscillations the velocity of the positive ions is increased at the anode layer, and during the other half period the velocity of the negative ions is increased, due to the changes in the electric force acting upon them. Then regardless of the sign of the change of the velocities the potential drop across the variation layers (which varies with the square of these changes) will be increased during the entire passage of the oscillation train.

The layer will act during this interval like a condenser, the potential drop across which is momentarily increased, which momentary increase will disappear with the passage of the wave-train. It will be as though the plates of a charged air condenser were suddenly further separated and then brought

suddenly back to their normal positions; or as though the specific inductive capacity of the dielectric were decreased and then increased. This operation being repeated for every spark at the transmitter a listener in the telephone in the *B* circuit will hear a sound whose pitch is exactly that of the spark, while an ammeter in that circuit will show no variation in its deflection.

As the fall of potential across the variation layers is proportional to the square of the current passing and to that of the impelling electric force, it is readily understood how, by regulating the heating current and the *B* voltage, an optimum value of the electrode drop may be obtained for which the effect from any given received impulses will be a maximum. Also how by varying the distance between the electrodes the sensitiveness of response may be regulated.

Thomson states that the current between two plates for a given difference of potential varies inversely as the cube of the distance between the plates, up to the saturation-current stage. But in the case of the Audion, where the cathode is an incandescent filament, the law seems to be quite different. Thus for two anodes of equal area, one approximately four times as far from the filament as the other, the two currents were as 21 to 8. The flux here varies more nearly as the inverse distance.

The potential difference required to produce saturation is proportional to the square of the distance between plates and to the square root of the intensity of ionization. This latter depends on the temperature of the filament.

In the case of the parallel plates, only one of which is incandescent, or if both are heated but below yellow heat so that only ions of one sign (positive) are present and carrying the current, then this current as Thomson shows is:

$$i = \frac{9 \text{ R V}^2}{32\, \pi\, d^3}$$

where R is the velocity of the ion under unit electric force, V the potential difference, D the distance between the two plates. According to this formula the current varies inversely as the cube of this distance. But this formula will hold only when R is independent of X, which it will not be when the temperature through the space is not uniform. It holds also only for currents that are small compared with their saturation values, for the saturation currents depend not upon the velocity of the ions

but upon the number of ions produced in unit time at the surface of the hot electrode.

But in the case of the Audion with small potentials, the closer the electrodes are together the more rapidly will the *B* current increase as the potential drop is increased. The trajectories of the ion are shorter and they therefore undergo fewer collisions, reunions, and retardations when the electrodes are close together.

In an Audion where the anode is far from the filament the saturation current is not attained with the *B* voltages used with the Audion in wireless telegraphy. We sometimes have instead its inverse counterpart, a saturation voltage, so to speak. As shown in the curve, at potentials from 10 to 18 volts a slight potential increment is accompanied by a very large increase in flux. And within these limits the sensitiveness of electric oscillations may be a maximum. The cusp points when present are generally found near these points of inflection in the flux-voltage curves.

In some cases a remarkable lag or "creeping effect" is observed at this saturation stage. As shown in the curve, the milliammeter needle crept slowly up after *B* was raised to 14 cells, from 18 to 26 divisions. The current flux required something like 15 seconds in this instance to attain its full value. The filament in this case may have been undergoing some change which caused it slowly to discharge more and more corpuscles until that stage was reached where the recombination of oppositely charged ions in the gas exactly equalled the output of negatively charged ones from the incandescent surface. Sometimes this creeping is accompanied by a loud frying sound in the telephone.

Magnetic Effects.

Thomson shows that at low gas pressures and high ionic velocities the ions, when placed in a strong magnetic field, will travel along the lines of strong magnetic force; but when the product of velocity and field is small the ion moves parallel to the electric force. If both magnetic and electric forces are uniform, the ions both positive and negative will move in the same direction and perpendicular to both E and H. When the electric field is not uniform but radiates from a point, and the magnetic field is uniform, the ion will describe a spiral traced on a cone of revolution whose axis is parallel to the magnetic field.

If the direction of E and H coincide, the path of the ion itself is a helix of gradually increasing pitch, with its axis parallel to the lines of magnetic force. The radii of the spirals will be small compared to the length of the mean free path of the ions. This is especially true for the negative ions, even when the motion of the positive ions is but little affected by the magnetic field.

If the electric field is not uniform (and it is not in the Audion where the negative charge is located on the small cylinder of the filament instead of on a plane surface) the paths of the ions will not be cycloids, but in any case the ions will be turned back by the magnetic field after traveling a certain distance d, from their source. Thus they will never get further than d from their source.

When the lines of magnetic force are perpendicular to the discharge in the cathode-ray tube, the magnetic field at all pressures retards the discharge and diminishes to a considerable degree the great drop in the electric force which occurs in the negative glow.

In general it can be assumed that in a strong magnetic field the ions tend to follow the lines of magnetic force. The smaller the velocity of projection the more nearly does the path of the ion coincide with a line of magnetic force. In cathode-ray tubes the boundary of the negative flow may coincide with the lines of magnetic force.

In the case of the Audion if the lines of a strong magnetic field pass through the gas parallel to the plane of the anodes, a marked reduction in the flux is obtained, sometimes amounting to 20 per cent. This effect is greater when the south pole of the magnet is nearest that leg of the filament which is attached to the negative terminal of battery A. The negative charge on this leg is of course greater than on the other. for the negative charge on the other is the resultant of the negative potential of battery B and the positive potential of battery A. And when the lines of magnetic force are so directed as to tend to sweep some of the negative ions off from the parts of the anode nearest to the filament leg which carries the greater negative potential, the reduction of the flux across the gas will be the greatest possible. Hence the magnetic polarity observed.

If the filament extend above the top of the anode, say for 0.5 cm., then a magnetic field parallel to the filament legs may

tend to force certain lost ions into a downward trajectory so that they will strike upon the anode instead of passing off above it. In this case only is an increase in the *B* flux observed as a magnet is brought up to the Audion.

In general the flux will be diminished by the magnetic field. When the magnetic lines pass perpendicular to the plane of the wings the negative ions which are traveling in the direction of the magnetic force, from filament to wing, will be accelerated, but those originally traveling out from the filament in the opposite direction will be bent around or deflected from their direct paths; so the resultant will be a decrease of the total current flux.

When the field is intense, a marked frying or hissing sound in the telephone is heard, especially with the two-wing anode, and when the magnetic force is parallel to their plane and thus affecting mostly the ions which are streaming towards their vertical edges. In the hissing arc parts of the arc are in rapid motion in the unstable portion around the edges of the positive terminal. Possibly also the presence of oxygen in the gas enters into the phenomena here as it does in those of the hissing arc. As the magnetic field lengthens the arc so here it lengthens the paths of the ionic discharge.

The hissing is much more violent when the surfaces of the anode instead of being plane are punched full of little holes whose ragged and protruding edges offer a greatly increased opportunity for the ions to travel irregularly under the combined forces of the magnetism and of the electric charges heaped up at all such points and edges. In this particular Audion I could get a great range of singing or squeaking sounds as the heating current was varied. Where the velocity of the ions is a maximum their deflections by the magnetic field will be lessened.

If the *B* flux is too great to give maximum sensitiveness of response, bringing up a magnet to the Audion will increase the strength of the wireless signals, because of the reduction of the *B* flux. Or if this flux be already below the optimum then the presence of the magnet may decrease the sensitiveness. This effect may be more pronounced for one wave-frequency than another, in which case the Audion can be attuned by regulating the magnetic field to which it is subjected.

Consider the case where the electric oscillations instead of being introduced into the Audion through its interior anode are

brought up to a metal plate outside a vessel. Electric displacement currents instead of conduction currents must then act upon the ions within the vessel and on the charges upon the electrodes.

Now in the case of an electromagnetic wave, where H and E are perpendicular to each other and to the direction of propagation, Thomson shows that if the product of $H \times e$ is large (e being the electric charge on a carrier) the average velocity of the ion parallel to the direction of E is zero, and the wave will carry the ion along with it. When however $H \times e$ is small (no external magnetic field) the effect of the hertzian wave will be to superimpose on the undisturbed motion of the ion a small vibratory motion parallel to the electric force in the wave and thus perpendicular to its direction of propagation.

A very convenient form of Audion for investigating the relations which the distance, area, etc., of the electrodes bear to its response is had by using a pool of mercury for the anode. This is conveniently held in one or more pockets blown in the walls of the glass vessel, and the filament so placed as to pass closer to some than to others.

Quite frequently I obtain with this arrangement two maxima of sensitiveness to the same transmitter, the filament heating current remaining unchanged; thus one maximum for $B = 12$ volts and a second for $B = 18$ volts. Again the sensitiveness is maximum when the mercury surface is as near as possible to the filament. When a globule has rolled out of its pocket, exposing a new surface for the anode, sometimes half a second elapsed before the sensitiveness is again restored. This form of mercury tube was especially sensitive to the influence of a magnetic field.

The optimum or critical voltage of B becomes less after this Audion has been heated a little time, as though the heated mercury vapor began to act to increase the conductivity of the gas. This critical voltage keeps reducing as the vaporization proceeds, and with a sudden jar on the tube I can bring this down, one cell of B at a time, accompanied by a loud click in the telephone at each reduction. Sometimes a similar reduction of the B flux amounting to as much as 25% can be obtained with the double platinum wing type of Audion, by striking it smartly; or a sudden increase in the flux may be obtained.

The heating current when a large anode surface is used is less than that required to produce the same degree of sensitive-

ness with a small pool of mercury as anode. In general the flux is quite proportional to the area of the anode, other conditions remaining unchanged. A mercury arc also may be substituted for the filament, but such an arrangement is apt to be noisy in the telephone.

When the hertzian oscillations are passed through the filament instead of through the gas, they require to be of great intensity to give any response whatever. Any results from the added heating effect which they may contribute to the filament are quite insignificant. The response when the Audions are connected up in parallel, or series, is always less than for one used alone.

In a tube whose two-plane anodes are fitted on hinges and backed with small iron disks so that their distances from the filament can be regulated by an external magnet, I find the response to a long wave-length greatest when this distance is the greatest possible; while to a wave-length of about one half this, the response is decidedly better when the wings are nearer to the filament. Of course the B flux is greater in this latter case, other conditions being unchanged; but the selective quality in this tube just described seems to be due to the regulations of the distance between anode and cathode rather than to other factors.

The manner in which the Audion should be located in the oscillating circuit, as well as many other considerations, show conclusively that it is a "potential-operated" rather than a "current-operated" relay receiver. At the same time its advantageous sluggishness of action, as explained above, renders it additive in its response to the energy of an entire wave-train or even of a series of wave-trains. Hence its excellent and marked selective qualities.

A large number of experiments have been carried out with a view to reducing the filament heat necessary to give the enclosed type of the Audion the extreme sensitiveness which now characterizes it. This is now attained at normal brilliancy of the filament, or a little below; never at excessive heats. Thus the life of an Audion should be that of an incandescent lamp of the same class of filament and voltage.

Filaments have been coated with alkali metals or salts, or vapors of these introduced into the tubes. Experiments along these lines and with various dissociable gases are being pushed with gratifying promise of our soon being able to achieve the

present marked sensitiveness even at read heats; or of still further multiplying the sensitiveness.

Radioactive compounds, applied for example between juxtaposed metal disks and heated, give little encouragement. At the low voltages used no increase of conductivity by their means has been observed, although Swinton has found that a radium coated cathode in a cathode-ray tube has a marked action in facilitating a luminous cathodic discharge, when the cathode is heated to redness. The mere presence of radium in the tube is insufficient to produce the effect.

Spontaneous ionization, that is the ionization independent of the electric field, as for example that produced by the X-rays does not increase the current flux. Only the ions produced by the electric field itself close to the cathode, and by the heat of the cathode, is effective.

It is required that the Audion be made with scrupulous care; a trace of impurity in the gas may produce surprisingly large effects in the potential drop across the variation layer The presence of a mere trace of moisture may cause great difference in the behavior of a tube.

In all this work a bewildering host of new and puzzling phenomena is continually encountered By its nature clean and pretty, fascinating in its ever new phases, gratifying in the efficiency with which it responds to the difficult demands of a new and intricate art, the Audion combines infinitely delicate matter and forces, at once offering rich fields for study to the physicist and delight to the practical man.

WIRELESS TELEPHONY

R[eginald] A. Fessenden

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WIRELESS TELEPHONY

BY R. A. FESSENDEN

Synopsis

A. Preface

The discussion of the theory, practical operation, and possibilities of wireless telephony is facilitated by first briefly considering the history of the development of wireless signaling generally.

B. Brief History of the Development of Wireless Signaling

1. *Introduction.* In preparing this note it has been considered best, for the sake of accuracy, to refer to published results, such as scientific articles or theses or patent specifications. For the sake of brevity, references to work done in repetition of previously published work has as a rule been omitted. So far as possible, the expression of personal opinion has been avoided in this section of the paper, the object being to gather together in concise form the facts known in regard to the development of the art. With the exception of Munk's original paper, which could not be obtained, all references have been verified by consulting the original publications, a work of some labor, and if any omissions or mistakes have been made data for their correction will be much appreciated.

2. *Period* 1838–1897. *Origin and Development of Old or Damped Wave-coherer Method.* Joseph Henry, to whose work the development of wire telegraphy owes so much, was the first (1838–1842) to produce high frequency electrical oscillations, and to point out and experimentally demonstrate the fact that the discharge of a condenser is under certain conditions oscillatory, or, as he puts it, consists "of a principal discharge in one direction and then several reflex actions backward and forward, each more feeble than the preceding until equilibrium is attained".[1]

This view was also later adopted by Helmholz[2] but the mathematical demonstration of the fact was first given by Lord Kelvin in his paper on "Transient Electric Currents".[3]

In 1870 Van Bezold discovered and experimentally demonstrated the fact that the advancing and reflected oscillations produced in conductors by a condenser discharge gave rise to interference phenomena.[4]

1. Scientific Writings of Joseph Henry, Smithsonian Institution.
2. Helmholz "Erhaltung der Kraft", Berlin, 1847.
3. Kelvin, *Philosophical Magazine*, June, 1853.
4. Van Bezold, *Poggendorff's Annalen*, 140, p. 541.

In 1883 Professor Fitzgerald suggested at a British Association meeting[1] that electromagnetic waves could be generated by the discharge of a condenser, but the suggestion was not followed up, possibly because no means was known for detecting the waves.

Hertz[2] discovered a method of detecting such waves by means of a minute spark-gap and before March 30, 1888, had concluded his remarkable series of researches in which for the first time electromagnetic waves were actually produced by a spark-gap and radiating conductor and received and detected at a distance by a tuned receiving circuit.

Hertz changed the frequency of his radiated waves by altering the inductance or capacity of his radiating conductor or antenna, and reflected and focused the electromagnetic waves, thus demonstrating the correctness of Maxwell's electromagnetic theory of light.

Lodge later in the same year read a paper on the "Protection of Buildings from Lightning"[3], before the Society of Arts, in which he described a number of interesting experiments on oscillatory discharges.

Great interest was excited by the experiments of Hertz, primarily on account of their immense scientific importance. It was not long, however, before several eminent scientists perceived that the property possessed by the Hertz waves of passing through fog and material obstacles made them particularly suitable for use for electric signaling.

Professor Elihu Thomson in a lecture delivered at Lynn, Mass., on "Alternating Currents and Electric Waves", in 1889, suggested this use.

Sir William Crookes in the *Fortnightly Review* for February, 1892, discussed the matter in some detail. I quote his statement in full as it shows what a clear conception he had of the possibilities and obstacles to be overcome:

> Here is unfolded to us a new and astonishing world, one which it is hard to conceive should contain no possibilities of transmitting and receiving intelligence.
>
> Rays of light will not pierce through a wall, nor, as we know only too well, through a London fog. But the electrical vibrations of a yard or

1. Fitzgerald "On a method of producing Electromagnetic Disturbances of comparatively short wave lengths" *Report of British Association*, 1883.

2. Hertz "Electric Waves".

3. Lodge *Society* of *Arts*, 1888.

more in wave length of which I have spoken will easily pierce such medium, which to them will be transparent. Here, then, is revealed the bewildering possibility of telegraphy without wires, posts, cables, or any of our present costly appliances. Granted a few reasonable postulates, the whole thing comes well within the realms of possible fulfilment. At the present time experimentalists are able to generate electrical waves of any desired wave-length from a few feet upwards, and to keep up a succession of such waves radiating into space in all directions. It is possible, too, with some of these rays, if not with all, to refract them through suitably shaped bodies acting as lenses, and so direct a sheaf of rays in any given direction; enormous lens-shaped masses of pitch and similar bodies have been used for this purpose. Also an experimentalist at a distance can receive some, if not all, of these rays on a properly constituted instrument, and by concerted signals messages in the Morse code can thus pass from one operator to another What, therefore, remains to be discovered is—firstly, simpler and more certain means of generating electrical rays of any desired wave-length, from the shortest, say of a few feet in length, which will easily pass through buildings and fogs, to those long waves whose lengths are measured by tens, hundreds, and thousands of miles; secondly, more delicate receivers, which will respond to wave-lengths between certain defined limits and be silent to all others; thirdly, means of darting the sheaf of rays in any desired direction, whether by lenses or reflectors, by the help of which the sensitiveness of the receiver (apparently the most difficult of the problems to be solved) would not need to be so delicate as when the rays to be picked up are simply radiating into space in all directions, and fading away according to the law of inverse squares.

I assume here that the progress of discovery would give instruments capable of adjustment by turning a screw or altering the length of a wire, so as to become receptive of wave-lengths of any preconcerted length. Thus, when adjusted to 50 yards, the transmitter might emit, and the receiver respond to, rays varying between 45 to 55 yards, and be silent to all others. Considering that there would be the whole range of waves to choose from, varying from a few feet to several thousand miles, there would be sufficient secrecy, for curiosity the most inveterate would surely recoil from the task of passing in review all the millions of possible wave-lengths on the remote chance of ultimately hitting on the particular wave-length employed by his friends whose correspondence he wished to tap. By " coding " the message even this remote chance of surreptitious straying could be obviated.

This is no mere dream of a visionary philosopher. All the requisites needed to bring it within the grasp of daily life are well within the possibilities of discovery, and are so reasonable and so clearly in the path of researches which are now being actively prosecuted in every capital of Europe that we may any day expect to hear that they have emerged from the realms of speculation into those of sober fact. Even now, indeed, telegraphing without wires is possible within a restricted radius of a few hundred yards, and some years ago I assisted at experiments where messages were transmitted from one part of a house to another without an intervening wire by almost the identical means here described.

The statement in the last paragraph of the quotation refers to the work of Professor David E. Hughes.[1] Professors Elihu Thomson and E. J. Houston in 1876 made a number of experiments and observations on high frequency oscillatory discharges.[2]

Professor Dolbear also suggested the same thing in an article in Donahoe's Magazine, March, 1893.

In fact the idea of using Hertzian waves for wireless telegraphy seems to have been quite widespread in the years immediately following Hertz's publications.

Fairly efficient means of generating electromagnetic waves of any desired length had been made known by Hertz. Vertical antennas connected with the ground had been previously used for sending and receiving by Dolbear in 1882 in connection with his system for telegraphing by electrostatic induction[3] and also later by Edison and others.

Hertz's receiver, the minute spark-gap, was not suited for wireless telegraphy and before any telegraphic work could be done a suitable receiver had to be found.

The fact that tubes containing conducting powders had their resistance altered by the discharge of a Leyden jar and that the original resistance could be restored by tapping the tube was first noted by Munk in 1835.[4]

In 1890 Branly showed that such a tube would respond to sparks produced at a distance from it.[5]

In 1892, at the meeting of the British Association at Edinburgh, Professor George Forbes suggested that such a tube would respond to Hertzian waves.

In 1893 Professor Minchen demonstrated experimentally that such powders would respond to electromagnetic waves generated at a distance.[6] He used a battery and galvanometer shunted around the powder to detect the effect of the waves.

Sir Oliver J. Lodge on June 1, 1894, delivered a lecture before the Royal Institution.[7] In this remarkable lecture Lodge described among other things the following:

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1. For Report of this work see *Electrician*, May 5, 1899.
2. *Journal Franklin Institute*, April 1876.
3. Dolbear U. S. patent 350,299, March 24, 1882.
4. See Guthe "Coherer action" *Transactions of the International Electrical Congress*, St. Louis, 1904, page 242.
5. Branley, *Comtes Rendues*, 1890, page 785, and 1891, page 90.
6. Minchen, *Proceedings Physical Society*, London 1893, page 455.
7. Sir O. J. Lodge, "The Work of Hertz", *Proceedings Royal Institution*, June 1, 1904, Vol. 14, page 321.

1. The filings coherer.

2. The filings coherer in hydrogen under reduced pressure (this in a note added July, 1894).

3. The automatic tapper back for the coherer.

4. The metallic reflector for focusing the waves.

5. The connection of the coherer to a grounded conductor; *i.e.*, a gas pipe system.

6. The method of making the coherer so connected respond by setting up oscillations in a separate grounded system, *i.e.*, a hot-water pipe system, in another part of the building.

7. The method of detecting distant thunder storms by connecting the coherer to a grounded gas pipe system.

In this lecture Professor Lodge stated that in his estimate the apparatus used would respond to signals at a distance of half a mile.

Early in 1895 Professor Popoff[1] of Cronstadt, Russia, constructed a very sensitive filings coherer, one form of which was used in some surveying experiments by the Russian government,[2] consisting of iron filings suspended by a magnet and resting upon a metallic plate or cup. He used early in 1895, the automatic tapping back mechanism, and substituted for the galvanometer an ordinary telegraphic relay. He operated this apparatus at a distance by means of a large Hertzian radiator. One terminal of his coherer was connected to a conductor fastened to a mast about 30 ft. high on the top of the Institute building and the other terminal of the coherer was grounded.

At the conclusion of his paper, which is dated December, 1895, Popoff made the following statement "In conclusion I can express the hope that my apparatus, with further improvements of same, may be adapted to the transmission of signals at a distance by the aid of quick electric vibrations, as soon as the source of such vibrations, possessing sufficient energy, will be found."

Among other experimenters who were working on this subject at the same time may be mentioned Captain Jackson of the British Navy, and Mr. A. C. Brown.

Marconi, on June 2, 1896, filed a provisional specification[3]

1. *Journal Russian Physico-Chemical Society*, Vol.27. April 25,1895,

2. A. S. Popoff, " Apparatus for detection and registration of electrical vibrations ", *Journal Russian Physico-Chemical Society*, Vol. 28, Dec. 1895.

3. Marconi, Great Britain patent, 12,039, 1896.

showing two forms of apparatus, one similar to Lodge's 1894 apparatus using ungrounded aerials for both sending and receiving and the other for use " when transmitting through the earth or water " substantially identical with Lodge's 1894 and Popoff's 1895 apparatus, with tapper back etc., and the receiving antenna only being grounded.

Soon after, in July 1896, Marconi arrived in England and made a number of experiments for the English Post Office at Salisbury Plain and elsewhere, using ungrounded aerials and parabolic reflectors and succeeded in reaching nearly two miles.

On March 2, 1897, Marconi filed the complete specification in which was included a statement that the transmitting antenna also could be grounded.

Lodge filed a provisional specification[1] showing radiating spheres but no antenna on May 10, 1897. The complete specification filed on Feb. 5, 1898, shows as one form both antennæ grounded and also the use of an inductance wound in the form of a coil for the purpose of diminishing the rate of damping of the waves.

So far as is known little work was done in America during this period. The writer made some experiments in 1896 and in conjunction with two of his students, Messrs. Bennett and Bradshaw, did considerable work on receivers of various type in the winter of 1896 and spring of 1897, the results of which were incorporated in a thesis.[2]

3. 1898. *Return to First Principles and Foundation, on lines Antithetical to Old, of New or Sustained Oscillation-non-microphonic Receiver Method.* Up to the year 1898, as may be seen from the above, the development of wireless telegraphy had proceeded along a single line. In that year, however, an entirely new method of wireless telegraphy was developed, characterized by a return to first principles, the abandonment of the previously used methods and by the introduction of methods in almost every respect their exact antitheses.

While the coherer is of more or less interest theoretically it is not adapted for use for telegraphic purposes. Responding as it does to voltage rises above a certain limit it does not discriminate between impulses of different characters, and is therefore peculiarly susceptible to interfering signals and atmospheric disturbances, and the operation of coherer systems cannot be

1. Lodge, Great Britain, patent, 11,575, 1897.
2. Western University of Pennsylvania, May, 1897.

guaranteed during the summer months or in the tropics. Roughly speaking a coherer acts by starting an arc and making a short-circuit on the line every time a signal is received, which short-circuit persists until it is broken by a blow from an additional mechanism, and such a method of operation is obviously far from practical. In addition it is practically impossible to obtain sharp tuning in a local circuit containing a coherer; its action is always more or less erratic, its electrostatic capacity variable, and it is insensitive.

At the sending end the energy which can be liberated by the discharge of an antenna is limited and in the form used prior to 1897 the dampening is so great that there are only a few oscillations per spark.

Lodge[1] by placing a coil of large inductance in the antenna throttled down the amount of energy radiated per oscillation and so obtained with the same limited amount of energy derived from the charged antenna, an increase in the time of dampening.

Braun[2] patented the method of using a local oscillatory circuit connected to an antenna, the local oscillatory circuit having a much longer period than the natural period of the antenna and of a different order of magnitude. Such a system, however, does not radiate energy appreciably, and produces a damped wave.

This dampening and the limited amount of energy obtainable by charging and discharging the antenna operates to prevent sharp tuning and working over long distances.

The coherer is well adapted for working with damped waves, but the coherer-damped wave method can never be developed into a practical telegraph system. It is a question whether the invention of the coherer has not been on the whole a misfortune as tending to lead the development of the art astray into impracticable and futile lines and thereby retarding the development of a really practical system.

The fact that no coherer-damped wave system could ever be developed into a practically operative telegraph system, and the fact that it was necessary to return to first principles and initiate a new line of development along engineering rather than laboratory lines was perceived in America in 1898[3] and a

1. Lodge, Great Britian, patent 11,575, 1897.

2. Braun, German patent 11,578, Oct. 14, 1898.

3. *Proceedings American Institute of Electrical Engineers*, Nov. 1899, p. 635 and Nov. 20, 1906, p. 781.

new method was advised which may be called the Sustained Oscillation-non-microphonic Receiver method as opposed to the Damped Oscillation-coherer method previously used.

4. *Fundamental Differences between the Old and New Wireless Schools.* The differences between the two methods are shown in tabulated form:

Damped Oscillation-coherer Method	Sustained Oscillation-non-microphonic Method.
A1: Damped oscillations are produced at the sending end.	A1: Sustained oscillations are produced at the sending end.
2: The energy transmitted is obtained by charging the antenna and discharging it.	2: The energy transmitted is derived from a local source and not from the antenna.
3: A spark gap is used for producing the oscillations.	3: An arc or high frequency dynamo is generally used for producing the oscillations.
B1: Imperfect or microphonic contact receivers are used.	B1: Non-microphonic contact receivers are used.
2: The action of the receiver depends upon the voltage rise and is independent of the amount of energy received.	2: The receiver response is determined by the integral amount of energy received.
3: An open tuned circuit is used for receiving.	3: A closed tuned circuit is used for receiving.
4: The receiving circuit is tuned to the wave frequency only.	4: The receiving circuit may be tuned to a group frequency as well as to the wave frequency.
C1: In transmitting messages the production of the electromagnetic waves is intermittent.	C1: The waves are preferably generated continuously and the transmission accomplished by changing the character of the wave.
2: The wave energy flux is intermittent.	2: The wave energy flux is constant.
3: A high voltage is used.	3: A low voltage is used.
4: Comparatively short wave lengths are used.	4: Comparatively long wave lengths are used.

5:	The signals consist of dots and dashes, whose interpretation is fixed.	5:	The signals may consist of dots only, whose interpretation depends on the station sending and receiving.
D1:	Antennæ are used adapted, roughly speaking, to utilize the electrostatic component of the electromagnetic waves.	D1:	The antennæ are preferably arranged so as to utilize the other component of the electromagnetic waves instead of the electrostatic component.

The history of these two antithetical lines of development will be treated of separately.

5. *Period* 1898–1902 A. *Development and Perfecting of Sustained Oscillation-non-microphonic Receiver Method* (a) *The current-operated receiver.* The first essential for the development of the system was, of course, a quantitatively responsive receiver. Several forms of this were tried including the modification of the Boys' radio-micrometer (consisting of a light thermo couple suspended in the field of a permanent magnet and heated by radiation from a wire which in turn was heated by the current to be detected) described by the writer at the Columbus meeting of the American Association in 1897.[1] This was abandoned in favor of Professor Elihu Thomson's alternating-current galvanometer[2] suitably modified for telegraphic work.[3]

Among other forms of current-operated receiver may be mentioned the following.

The *Hot-wire Barretter*,[4] consisting of a minute platinum wire a few hundred thousandths of an inch in diameter and approximately a hundredth of an inch in length. The term " barretter " was coined for this device for the reason that it differs essentially from the bolometer of Langley in that it is arranged to be affected by external sources of radiant heat as little as possible instead of as much as possible, and, to have an extremely small specific heat, an object not sought in the case of the bolometer.

The *Liquid Barretter*[5] in which the change of resistance is effected by heating a liquid, the concentration of path being obtained by means of a fine platinum wire point. Some question

1. *Electrician*, June 24, 1904.
2. Elihu Thomson, U. S. patent 363,185, Jan. 26, 1887.
3. U. S. patents 706,736 and 706,737, Dec. 15, 1899.
4. U. S. patent 706,744, June 6, 1902.
5. U. S. patent 727,331, April 9, 1903.

has been raised as to the theory of operation of this device but I think there is no question but that the effect is due to heat, though what per cent. of the effect is due to change in ohmic conductivity by heat and what per cent. is due to depolarization by heat is still, as originally stated by the writer,[1] uncertain. The facts that the device operates practically equally well irrespective of which terminal is connected to the local battery, and that the effect varies as the square of the alternating current (as a heat operated device should do) instead of directly with the alternating current as a rectifier would do, and that depolarization is produced by the heat, have been confirmed by Dr. L. W. Austin.[2] The writer has experimentally determined the fact that though the electrical impulses may have a duration of less than a millionth part of a second the change in resistance persists for approximately the ten thousandth part of a second, which would seem to show conclusively that the action is not a *direct* effect of the waves.

(b) *Methods of Obtaining Sustained Oscillations.* 1. *Spark-gap and Local Oscillatory or "tank" Circuit.* Professor Elihu Thomson discovered that by using a transformer without an iron core (the well known Elihu Thomson air-core transformer, later used by Tesla and others), and a spark-gap and condenser in the primary circuit and with the secondary circuit suitably tuned great resonant rises of potential could be obtained. In 1892 he constructed such a transformer giving discharges 64 inches long.[3]

The same method was later used by Tesla[4] in his experimental researches and in his attempt to carry out Loomis'[5] method of transmitting a current through a hypothetical conducting stratum in the upper regions of the atmosphere.

The device, suitably modified for wireless telegraphic purposes, so as to give instead of a continuously cumulative rise of potential an initial rise of potential followed by a gradual feeding in of the energy from the local circuit to supply the energy lost from radiation, was made use of in 1898 for the purpose of producing prolonged trains of sustained waves.

Various types of connection between the antenna and the local oscillatory circuit were tested but it was found that the

1. *Ibid.*
2. Austin, *Bulletin of the Bureau of Standards*, Vol. 2 No. 2.
3. *Electrical World*, Feb. 20 and 27, 1892.
4. U. S. patent 645,516, Sept. 2, 1897.
5. Loomis, U. S. patent, 129,971, July 30, 1872.

most efficient results were obtained by connecting the local circuit directly across the spark-gap.[1]

The results of some comparative tests are here given. The figures in the column " A " are for the local circuit connected directly to the terminals of the spark-gap, those in column " B " are for an auto-transformer, those in column " C " for a loose coupled primary and secondary.

	A	B	C
Frequency	212,000	212,000	212,000
Tank capacity	0.072 m.f.	0.072 m.f.	0.072 m.f.
Kilowatt output dynamo	30	30	30
Tank current	400 amperes	370 amperes	300 amperes
Antenna current	48.5	46.	48.

The large station at Brant Rock is operated with the local circuit directly connected across the spark-gap, partly because the efficiency is somewhat greater, but also on account of the great simplification of connections and the fact that the degree of sustainment of the wave train may be adjusted very simply, if desired, by sliding the lower terminal of the antenna along a few inches of the lead of the local oscillatory circuit.

Cooper Hewitt[2] in 1902 used a modification of his mercury lamp to obtain intermittent discharges each followed by a train of high frequency oscillations.

2. *Arc methods.* The worker with high frequency oscillatory currents will soon discover that we are indebted to the genius of Professor Elihu Thomson for practically every device of any importance in this art.

The method of producing high frequency oscillations from an arc and continuous current was discovered by him in 1892.[3] Fig. 1, taken from his patent, shows the general form of his arrangement. If the directions given in the specification are followed no difficulty will be met with in obtaining frequencies as high as 50,000 per second.

Between 1900 and 1902 some experiments were carried out with the Elihu Thomson arc as a source of high frequency oscillations for wireless telegraphy and telephony.

Some difficulties were found, for example the arc could not be started and stopped as quickly as was necessary for telegraphic

1. U. S. patents 706,735 and 706,736, Dec. 15, 1899.
2. Cooper Hewitt, U. S. patent 780,999, April 25, 1902.
3. Elihu Thomson U. S. patent 500,630, July 18, 1892.

purposes and the intensity of the oscillations and their frequency varied considerably. These were overcome by making some minor improvements, for example the difficulty in sending was overcome by permitting the arc to run continuously and using the key to change the electrical constants of the circuits.[1] The difficulty in keeping the intensity and frequency constant was overcome by substituting resistance for a portion of the inductance, and also by using the arc under pressure.[2]

Tests made by Dr. Austin[3] show that with this method fre-

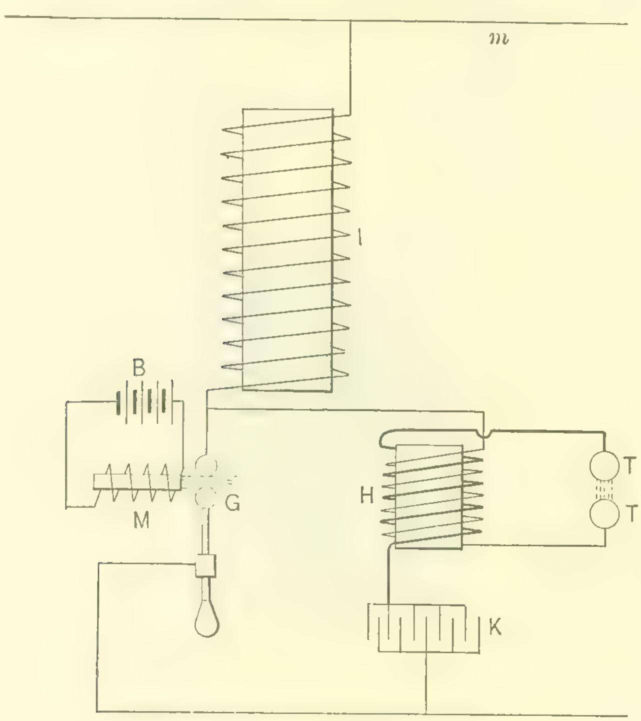

Fig.1

quencies as high as 3,000,000 per second and efficiencies as high as 60% can be obtained together with an absolutely steady generation of the high frequency currents and an absence of harmonic frequencies.

3. *High frequency alternator.* The first high frequency alternator was built by Professor Elihu Thomson in 1889.[4] And it

1. U. S. patents 706,742, July 6, 1902, 706,747, Sept. 28, 1901, 727,330, March 21, 1903, 730,753, April 9, 1903.

2. *Ibid* and U. S. patent 706,741.

3. Austin, *Bulletin of the Bureau of Standards*, Vol. 3, No. 2.

4. Thomson, *Elec.Engineer*, July 30,1890 and *London Elec.*,Sept.12,1890.

was while experimenting with it in 1900 that Dr. Tatum made his very interesting discovery that high frequency currents of large amperage could be passed through the body without injury.[1]

From 1898 to 1900 numerous experiments were made on antennæ of large capacity and it was found that instead of using sheets of solid metal or wire netting, single wires could be placed at a considerable fraction of the wave-length apart and yet give practically the same capacity effect as if the space between them were filled with solid conductors.

From other investigations on the variation of radiation with frequency the result was arrived at that it should be possible to construct an alternating-current dynamo of sufficiently high frequency and output to give ample radiation for wireless telegraphic purposes.[2]

FIG. A

In 1900 a large American electrical manufacturing company kindly consented to take up the construction of such a dynamo. As a preliminary, a dynamo of 1 kw. output and 10,000 cycles (shown in Fig. A) was built in 1902. By the summer of 1906 many of the difficulties had been overcome and a machine giving 50,000 cycles was installed at the Brant Rock station. Various improvements were made by the writer's assistants, and in the fall of 1906 the dynamo was working regularly at 75,000 cycles, with an output of half a kilowatt and was being used for telephoning to Plymouth, a distance of approximately 11 miles. In the following year machines were constructed having a fre-

1. Thomson, *Elec. Engineer*, March 11, 1891.
2. U. S. patent 706,737, May 29, 1901.

quency of 100,000 cycles per second and outputs of 1 and 2 kilowatts.

The credit for the development of this machine is due to Messrs. Steinmetz, Haskins, Alexanderson, Dempster, and Geisenhoner and also to the writer's assistants, Messrs. Stein and Mansbendel.

(*c*) *Closed tuned circuits.* In 1898 the open tuned circuits originally used were discarded for closed tuned circuits[1] and it was discovered that valuable selective effects could be obtained by placing the condenser in shunt to the inductance instead of in series with it.[2]

(*d*) *Combination of wave and group tuning.* The fact that if selectivity is obtained solely by tuning to wave frequencies, the number of stations is limited, was appreciated at an early date. In 1900[3] a new method was developed, the stations being tuned both to the wave frequency and to an independent or group frequency, so that stations might obtain selectivity by varying either the wave or the group frequency and thus have at their disposal a virtually unlimited number of combinations and be practically free from atmospheric disturbances. Fig. C shows a type of group tuner.

(*b*) *Further development of damped wave-coherer method.* Marconi by 1898 had carried the development of the filings coherer to its maximum point.

Lodge in 1897[4] had disclosed the open secondary circuit for receiving.

Marconi in 1898[5] greatly improved this by adjusting the length of the secondary so as to tune it, and by the aid of this improvement was enabled to telegraph a distance of 35 miles[6] in October, 1899.

Lodge in 1902[7] invented what is perhaps the most perfect form of coherer, consisting of a thin steel disc dipping in oil covered mercury and automatically decohered by being kept in continuous rotation.

A number of self-restoring coherers of which the Brown[8]

1. U. S. patents 706,735 and 706,736, Dec. 15, 1899.
2. *Ibid.*
3. U. S. patents 727,325, June 2, 1900, and 727,330 March 21, 1903.
4. Lodge, Great Britain patent, 11,575, May 10, 1897.
5. Marconi, Great Britain patent, 12,326, June 1, 1898.
6. Official report U. S. Navy of test U. S. S. Massachusetts, Oct. 1899.
7. Lodge, Muirhead and Robinson, Great Britain patent, 13,521, June 14, 1902.
8. Brown and Neilson, Great Britain patent, 28,955, Dec. 17, 1896.

carbon coherer may be taken as a type, including the mercury carbon coherer of Solari, came into more or less extended use, and also modifications of the imperfect contact receiver of Neugschwender.[1]

The small progress made along these lines is to be explained by the fact that the damped wave-coherer system is essentially and fundamentally incapable of development into a practical system.

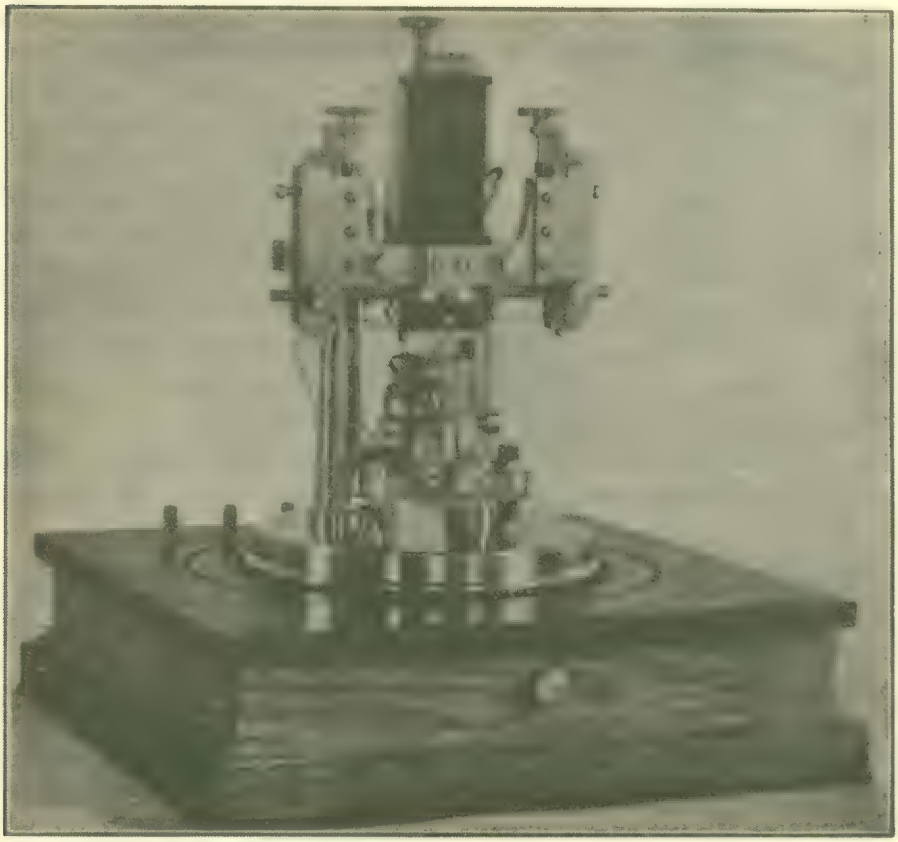

FIG. C.

Period 1902–1908—*Later Developments.* Progress in Europe since 1902 has been marked by the gradual abandonment of the elements of the damped wave-coherer system and the substitution of elements of the sustained wave non-microphonic contact type.

In 1900[2] Marconi substituted for the plain aerial an aerial

1. A. Neugschwender, *Wied. Ann. der Physik*, 1899, vol. 67, p. 430.
2. Marconi, Great Britain, patent, 7,777, Apr. 26, 1900.

with the writer's tuned local circuit or tank circuit for sending, thus obtaining a considerable increase in range of transmission.

In 1902, Marconi invented a very ingenious form of current operated receiver, called the magnetic detector[1], and with this combination achieved some very remarkable results.

In 1905 Professor Fleming[2] invented a very efficient detector based on the "Edison effect" in incandescent lamps, and the observations of Elster and Geitel[3] on the rectifying effect of such an arrangement on Hertzian oscillations.

Virtually nothing was done in Europe in the way of producing sustained oscillations by the arc or high frequency method until recently, possibly because of Duddell's erroneous statement[4] to the effect that frequencies much above 10,000 could not be obtained by the Elihu Thomson arc method, and Fleming's statement[5] that an abrupt impulse was necessary and that high frequency currents, even if of sufficient frequency, could not produce radiation.

In 1903 Poulsen[6] invented an interesting modification of the Elihu Thomson arc, which consists in forming the arc in hydrogen instead of in air or compressed gas as previously done. This modification is not, however, so efficient as the older methods and gives oscillations varying in amplitude and intensity and accompanied by strong harmonics,[7] but I have considered it worth mentioning on account of the amount of interest it appears to have excited in Europe.

Some very important and interesting papers on electrical oscillations were published during these years by Oberbeck,[8] Wien,[9] Drude,[10] and Bjerknes.[11]

In America the development of the sustained oscillation non-microphonic system has proceeded steadily and it may now be said to have reached the stage of commercial practicability.

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1. Marconi, Great Britain, patent, 10,245, 1902.
2. Fleming, *Proceedings Royal Society London*, 1905, Vol. 74.
3. Elster and Geitel, *Wied. Ann der Physic*, Vol. 52, page 433.
4. Duddell, *The Electrician*, 1903, Vol. LI, page 902.
5. Fleming, *Proceedings of the International Congress, St. Louis*, 1904, Vol. 3, page 603.
6. Poulsen U. S. patent 789,449, June 19, 1903.
7. Austin, *Bulletin of the Bureau of Staudards*, Vol. 3 No. 2.
8. Oberbeck Wied. *Ann. der Physik*, Vol. 55, 1895.
9. *Wied Ann. der Physik* Vol. 8, 1902.
10. Drude *Ann. der Physik*, Vol. 13, 1904.
11. Bjerknes, *Ann. der Physik*, Vol. 44, 1891, and Vol. 47, 1892.

On account of the amount of work which has been done it would be impossible to refer to more than a few of the recent advances.

The following are some of the later types of detectors:

The *frictional receiver*,[1] in which the waves produce a change of friction between two moving surfaces and so cause an indication.

The *heterodyne receiver*,[2] in which a local field of force actuated by a continuous source of high frequency oscillations interacts

Fig. B.

with a field produced by the received oscillations and creates beats of an audible frequency.

The so called *thermoelectric receivers* of Austin,[3] Pickard[4] and Dunwoody.[5]

The "*audion*" *of deForest*,[6] a very interesting and sensitive

1. U. S. application, 251,538, March 22, 1905.
2. U. S. application, 271,539, June 28, 1905.
3. Austin, U. S. application, 319,241, May 29, 1906.
4. Pickard, U. S. application, 342,465, Nov. 8, 1906.
5. Dunwoody, patent, 837,616, March 23, 1906.
6. deForest, U. S. patent, 836,070, Jan. 18, 1906.

device, which though superficially resembling Professor Fleming's rectifier appears to act on an entirely different principle.

The *Cooper Hewitt mercury receiver*, about which little is known but which appears to be very sensitive.

The following are some of the later methods of producing sustained oscillations:

The *substitution of a number of arcs in series having terminals of large heat capacity* in place of the single arc in the arc method.[1]

The *use of regulating or "fly-wheel" circuits* in connection with the arc method.[2]

The *method of producing oscillations* shown in Fig. B by

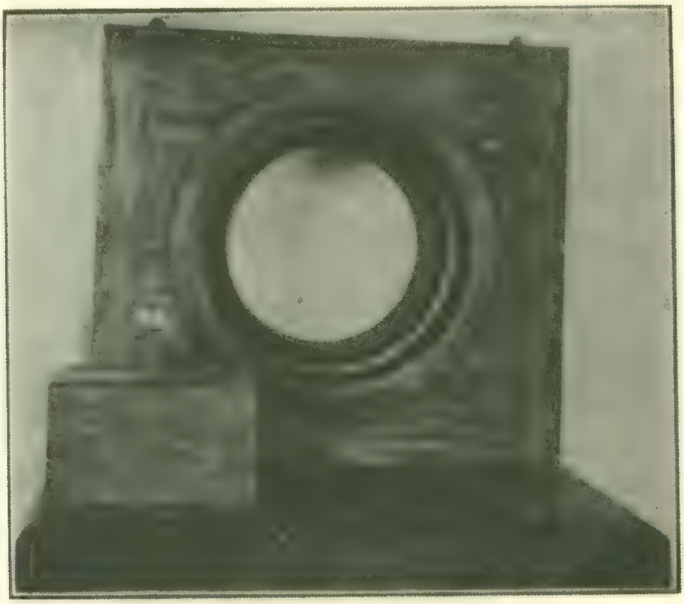

FIG. C.

using two arcs and throwing the discharge from one side to the other alternately at a frequency regulated by the constants of the electric circuit.[3]

The *condenser dynamo*[4] which consists of two radially slotted discs separated by a mica diaphragm, charged by a continuous current source of potential, and rotating in opposite directions.

Two-phase high frequency dynamo method.[5]

1. U. S. application, 291,737, Dec. 14, 1905.
2. *Ibid.*
3. *Ibid.*
4. U. S. application, 291,739, Dec. 14, 1905.
5. U. S. patent, 793,649, March 30, 1905.

Commutator method.[1] In this method the high frequency is produced by means of a ball rotating at high speed on the interior surface of a commutator. Shown in Fig. C.

The *helium arc method*[2] in which the arc is produced in helium or argon or similar gases.

The *critical pressure method*[3] in which the electrodes extend within a certain critical distance, depending upon the pressure used, so that the discharge always passes at the same voltage irrespective of the distance between the electrodes.

Methods of Signaling. Continuous production of waves but changing constants of sending circuit.[4]

The *inverted method* of sending and the method of signaling by sending dots, the interpretation of which is determined by similar commutators at the sending and receiving stations.

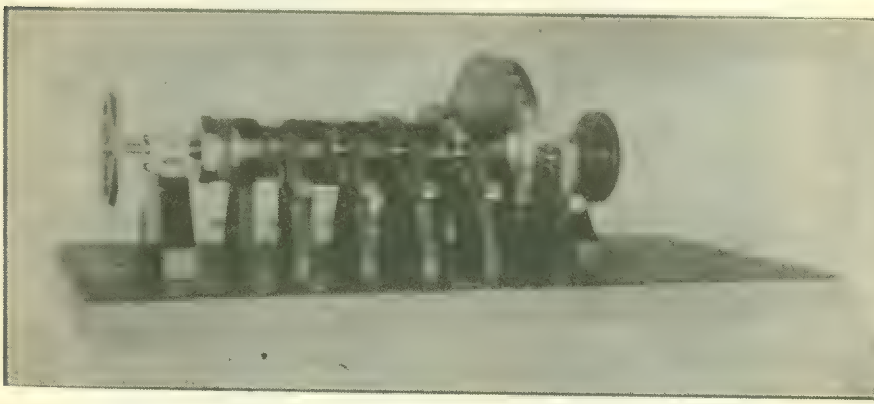

FIG. L.

Duplex and Multiplex Methods. A considerable number of these have been worked out, mostly operating either by balance methods[5] or commutators.[6] It is impossible to discuss all the various improvements, such for example as the method of indicating the busy and free state of a station, the methods of sending and receiving in one direction, the various types of aerials used for receiving the other components of the electromagnetic waves besides the electrostatic component, etc.

1. U. S. application, 316,521, May 12, 1906.
2. U. S. application, 351,560, Jan. 7, 1907.
3. U. S. application, 355,787, Feb. 4, 1907.
4. U. S. patents 706,747, Sept. 28, 1901; 706,742, June 6, 1902; 727,747, March 21, 1903.
5. U. S. application, 366,528, April 5, 1907.
6. U. S. patent, 793,652, April 6, 1905.

Fig. L shows the harmonic interrupter for determining the variation of intensity with change of note.

Fig. M shows a type of receiver described in U. S. Patent 706,747, in which the telephone diaphram is formed of thin copper and repelled by a fixed coil having a resistance of about 16 ohms. The principle of this receiver was discovered by Professor Elihu Thomson. It has been used for wireless telephony for a distance of 11 miles with fairly satisfactory results.

Fig. N shows a transformer used in the transmitting circuit. The number of primary and secondary turns can be altered continuously, and also the degree of coupling. The wire is wound off from an insulating cylinder onto a cylinder of copper, and the cylinder of copper, forming a closed circuit secondary

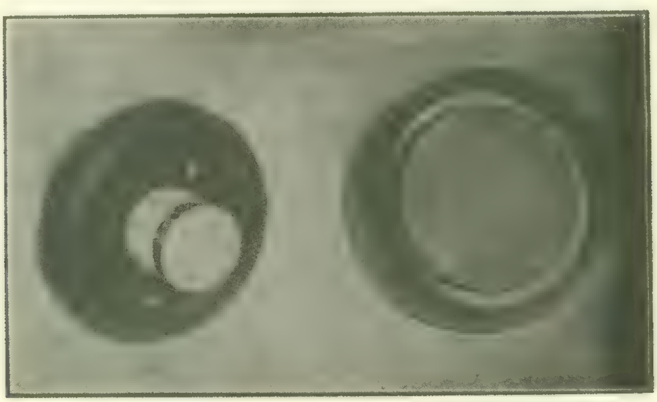

Fig. M.

of the transformer, annuls the inductance of that portion of the wire wound upon the copper cylinder.

Fig. O shows an apparatus for determining the best shape of coil for use with the heterodyne receiver.

Fig. P shows a group-tuned call; that is, a vibration galvanometer which operates a selenium cell and rings a bell when a call is received.

C. Theory of Wireless Telephony

For wireless telephony three things are necessary:

1. Means for radiating a stream of electrical waves sufficiently continuous to transmit the upper harmonics on which the quality of the talking depends.

2. Means for modulating this stream of waves in accordance with the sound waves.

3. A continuously responsive receiver giving indications proportional to the energy received, and capable of responding with sufficient rapidity to the speech harmonics.

Work on the wireless telephone was commenced before a satisfactory means was discovered for producing sustained oscillations.

To ascertain the number of sparks per second which was necessary to determine articulate speech, a phonograph cylinder was taken and grooves were cut in it longitudinally. It was found in this way that practical transmission could be accomplished with 10,000 breaks per second. It is believed now that this number is unnecessarily high, possibly owing to the fact

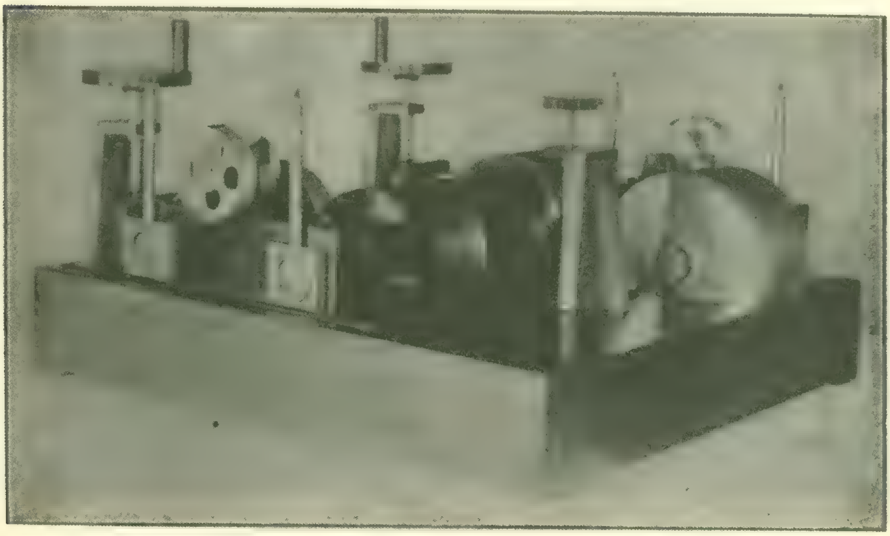

FIG. N.

that it was impossible to cut the grooves on the cylinder without producing ridges. The lower limit may be fixed in another way.

Electrical circuits met with in actual working have resistance, self inductance capacity, and leakance. Heaviside gave the differential equations for the pressure and current over such circuits when alternating voltages were applied, but no method of solution being known the mathematical treatment of such circuits was restricted to cases where one of the constants was neglected, until Dr. A. E. Kennelly in a masterly series of papers gave the complete solution.

The results were immediately found applicable to a great variety of problems, such as the transmission of signals through cables and of telephonic speech through various types of circuits.

In this way Dr. Kennelly[1] by comparing the results obtained by Dr. Hammond V. Hayes[2] in practical telephonic transmission over loaded lines with the theoretical values of the current for different harmonics showed that harmonics above 2,000 per second could be neglected for telephonic transmission.

The writer has never succeeded in obtaining good talking with such a low frequency, but under favorable conditions fairly satisfactory speech may be obtained with 5,000 interruptions per second. For really good transmission, however, the radiation must be practically continuous, for if the spark frequency is less than 20,000 per second there is a disagreeable high pitch

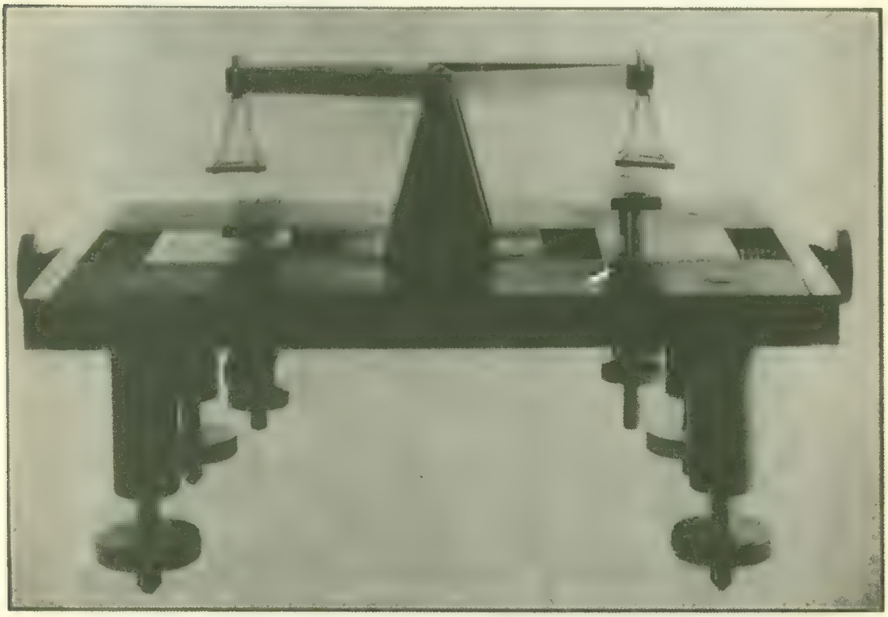

FIG. O.

note in the telephone, not noticeable perhaps at first but apt to become annoying with use. The most satisfactory way is, of course, to use a source of sustained oscillations.

It fortunately happens that for wireless telephonic purposes it is inadvisable to use a wave frequency of less than 25,000 per second, on account of the difficulty in radiating energy with low frequencies.

1. Kennelly, " Distribution of Pressure and Current over Alternating Current Circuits ", *Harvard Engineering Journal*, 1906, page 43.

2. Hayes, " Loaded Telephone Lines in Practice ", *Transactions International Electrical Congress*, St. Louis, Vol. 3.

Fig P.

The receiver must, of course, be continuously responsive. If, for example, it had to be tapped back in order to restore it to the responsive condition, speech could not be transmitted.

It must also give indications proportional to the energy received or the character of the speech will be distorted.

It must also respond with sufficient rapidity. If, for example, it takes a thousandth of a second to restore itself to its original resistance the receiver will obviously not record the higher harmonics. I have experimentally determined that a receiver which restores itself in the ten thousandth part of a second acts with sufficient rapidity.

D. History of the Development of Wireless Telephony

The writer has been asked on several occasions how the wireless telephone came to be invented. In November, 1899, shortly prior to the delivery of my previous paper,[1] while experimenting with the receiver shown in Fig. 3 of that paper, I made some experiments with a Wehnelt interrupter for operating the induction coil used for sending.

In the receiver mentioned the ring of a short-period Elihu Thomson oscillating current galvanometer rests on three supports, *i.e.*, two pivots and a carbon block, and a telephone receiver is in circuit with the carbon block. A storage battery being used in the receiver circuit[2] it was noticed that when the sending key was kept down at the sending station for a long dash the peculiar wailing sound of the Wehnelt interrupter was reproduced with absolute fidelity in the receiving telephone. It at once suggested itself that by using a source with a frequency above audibility wireless telephony could be accomplished.

Professor Kintner, who was at that time assisting me in these experiments and to whose aid their success is very largely due, was kind enough to make the drawings for an interrupter to give 10,000 breaks per second. Mr. Brashear, the celebrated optician kindly consented to make up the apparatus and it was completed in January or February, 1900.

The experimental work was, however, delayed as the writer was at that time transferring his laboratory from Allegheny, Pa., to Rock Point, Md., and it was not until six months later that the stations at that point were completed and a suitable mast was erected for trying the apparatus.

1. *Transactions American Institute Electrical Engineers*, Nov. 22, 1899.
2. U. S. patent, 706,736, December 15, 1899.

The first experiments were made in the fall of 1900 with the above mentioned apparatus which was supposed to give 10,000 sparks per second but which probably gave less. Transmission over a distance of one mile was attained but the character of the speech was not good and it was accompanied by an extremely loud and disagreeable noise, due to the irregularity of the spark.

By the end of 1903 fairly satisfactory speech had been obtained by the arc method above referred to, but it was still accompanied by a disagreeable hissing noise. In 1904 and 1905 both the arc method and another method in which the 10,000 cycle alternator above referred to was employed, had been developed to such an extent that the apparatus could be used practically and sets were advertised and tendered to the U. S. Government.[1] The transmission was, however, still not absolutely perfect.

By the fall of 1906 the high frequency alternator had been brought to a practical shape and was used for telephoning from Brant Rock to Plymouth, a distance of 11 miles, and to a small fishing schooner,[2] this being the first instance in which wireless telephony was put in practical use. The transmission was perfect

1. Letter of July 8, 1905; see *The Electrician*, London, Feb. 22, 1907; also catalogue of 1904 and subsequent.

2. An amusing instance may be mentioned as illustrating the incredulity with which the wireless telephone was received. Some of the local papers having published an account of the experiments with the schooner above referred to the following appeared under the heading "Current News and Notes" in the columns of a prominent technical journal, Nov. 10, 1906.

"A New Fish Story.—It is stated from Massachusetts that the wireless telephone has successfully entered into the deep sea fishing industry. For the last week experiments have been conducted by the wireless telegraph station at Brant Rock, which is equipped with a wireless telephone, with a small vessel stationed in the fleet of the South Shore fishermen, twelve miles out in Massachusetts Bay. Recently, it is asserted, the fishermen wished to learn the prices ruling in the Boston market. The operator on the wireless fitted boat called up Brant Rock and telephoned the fishermen's request. The land operator asked Boston by wire and the answer was forwarded back to the fishermen. This is a rather fishy fish story".

The doubt expressed was, however, only natural. I remember the astonishment displayed by one of the company's new operators some months previously on placing the receiving telephone to his head while the vessel was almost out of sight of land and hearing the operator at the land station call his name and begin to talk to him.

and was admitted by telephone experts to be more distinct than that over wire lines, the sound of breathing and the slightest inflections of the voice being reproduced with the utmost fidelity.

As it was realized that the use of the wireless telephone would be seriously curtailed unless it could be operated in conjunction with wire lines, telephone relays were invented both for the receiving and transmitting ends and were found to operate satisfactorily, speech being transmitted over a wire line to the station at Brant Rock, retransmitted there wirelessly by a telephone relay, received wirelessly at Plymouth and there relayed out again on another wire line. On Dec. 11, 1906, invitations were issued to a number of scientific men to witness the operation of the wireless transmission in conjunction with the wire lines.[1] A report of these tests appeared in the American Telephone Journal of Jan. 26 and Feb. 2, 1907, the editor being one of the men present.

In July 1907 the range was considerably extended and speech was successfully transmitted between Brant Rock and Jamaica, Long Island, a distance of nearly 200 miles, in daylight and mostly over land,[2] the mast at Jamaica being approximately 180 ft. high.

In 1907 several European experimenters succeeded in transmitting speech wirelessly, using some of the earlier forms of the writer's arc method, and some months ago the vessels of

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1. Brant Rock, Mass., Dec. 11, 1906.

American Telephone Journal, 100 William St., New York City.

Dear Sirs: A limited number of invitations have been issued to witness the operation of the National Electric Signaling Co's. wireless telephone system between Brant Rock and Plymouth, Mass., over a distance of between ten and eleven miles.

The tests will be as follows:

1. Transmission of ordinary speech, and also transmission of phonographic talking and music by wireless telephone between Brant Rock and Plymouth.

2. Transmission of speech over ordinary wire line to wireless station at Brant Rock, relaying the speech there automatically by telephone relay and automatically transmitting the speech by wireless to Plymouth, transmitting same at Plymouth automatically directly or by telephone relay over regular wire line.

Invitations have been issued to the following gentlemen, (here follows list of some of the guests, including Dr. A. E. Kennelly, Professor Elihu Thomson, etc., and a request to the company to send a representative).

Yours very truly,

National Electric Signaling Co.

2. "Long Distance Wireless Telephony," *The Electrician*, Oct. 4, 1907.

our Pacific squadron were equipped with wireless telephones, using this arc method, by another American company.

E. Methods and Apparatus

1. *Methods and apparatus for producing the electromagnetic waves.* These have been already referred to. Fig. 2 shows a rotating spark-gap giving approximately 20,000 discharges per second. This was connected to a 5,000-volt source of direct

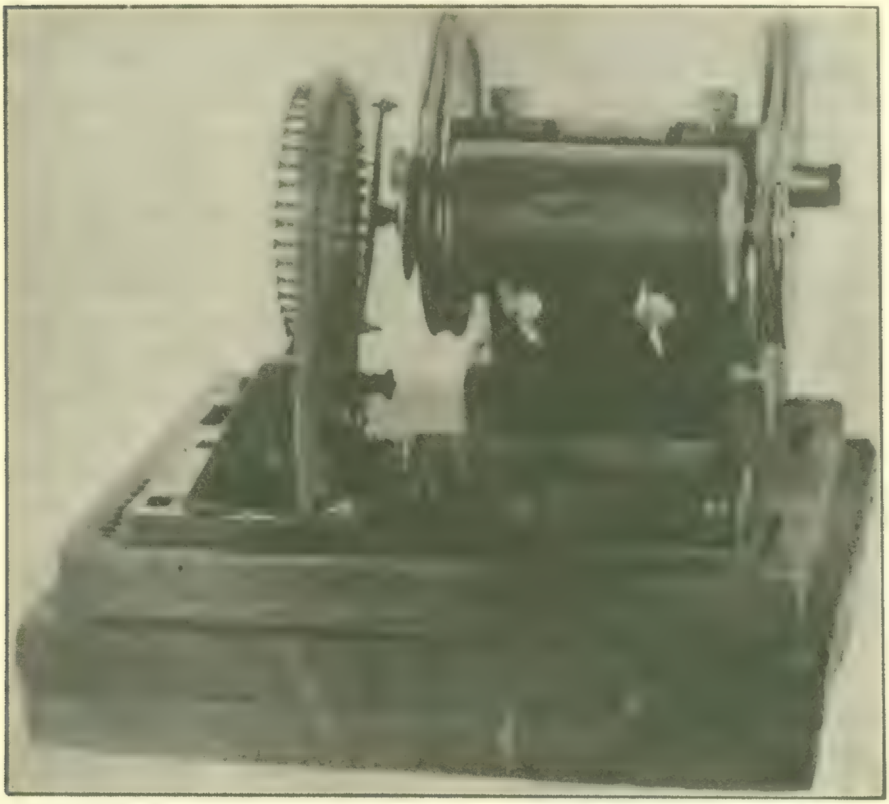

Fig. 2.

current. The terminals are of 40% platinum-iridium. In operation the apparatus is arranged to charge a condenser to a definite potential and discharge it.

Figs. 3 and 4 show forms of apparatus for operating the arc in a gas under pressure.

The apparatus of Fig. 4 is also used for the arc in vacuum and the critical distance arc.

Fig. 5 shows a multiple gap with rotating electrodes, brass, amalgamated zinc and graphite being used.

Fig. 6 shows a multiple arc gap with electrodes of different materials, the upper terminals being water cooled.

Fig. 7 shows a condenser dynamo.

Fig. 8 shows a general view of one type of high frequency

Fig. 3.

alternator. It is driven by a motor and a DeLaval gear. It has been operated at 96,000 cycles per second, but is generally run at 81,700.

Fig. 9 shows a field disc; it is 12 inches in diameter and there are 300 slots on it.

Fig. 10 shows the armature and field coils. There are 600 armature slots each containing two turns of 13 mil wire. The field current is 5 amperes. The resistance of the armature is

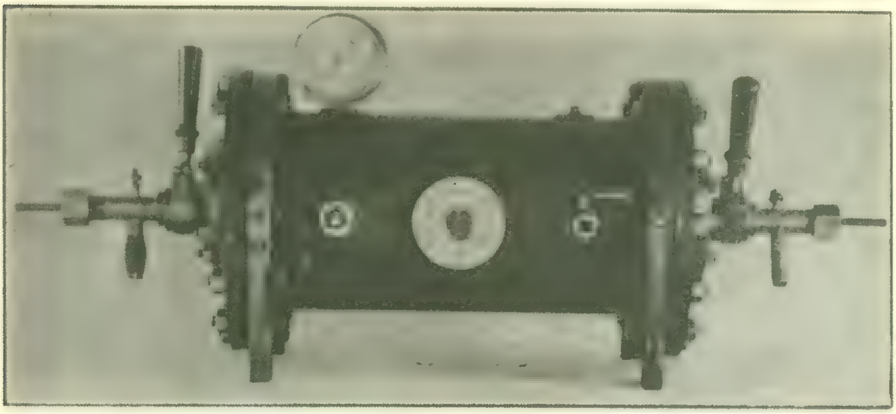

FIG. 4.

6 ohms; it gives 160 volts and about 7 or 8 amperes. Other armatures have been constructed having a resistance of 4 ohms. For some work double armatures are used giving about 270

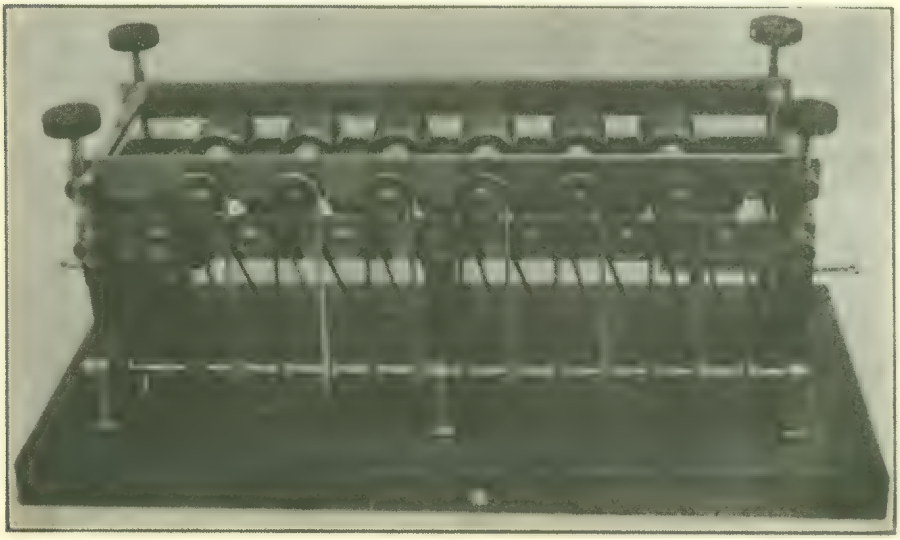

FIG. 5.

volts. The output of the single armature machines at 81,700 cycles is approximately one kilowatt. The output of the double armature machine is approximately 2 kilowatts.

Other types of high frequency alternators are under construction. One type shown in Fig. 11 is designed for use on shipboard. The armature disc is 6 inches in diameter and two armatures are used. It is arranged to be mounted on gimbals and to be driven

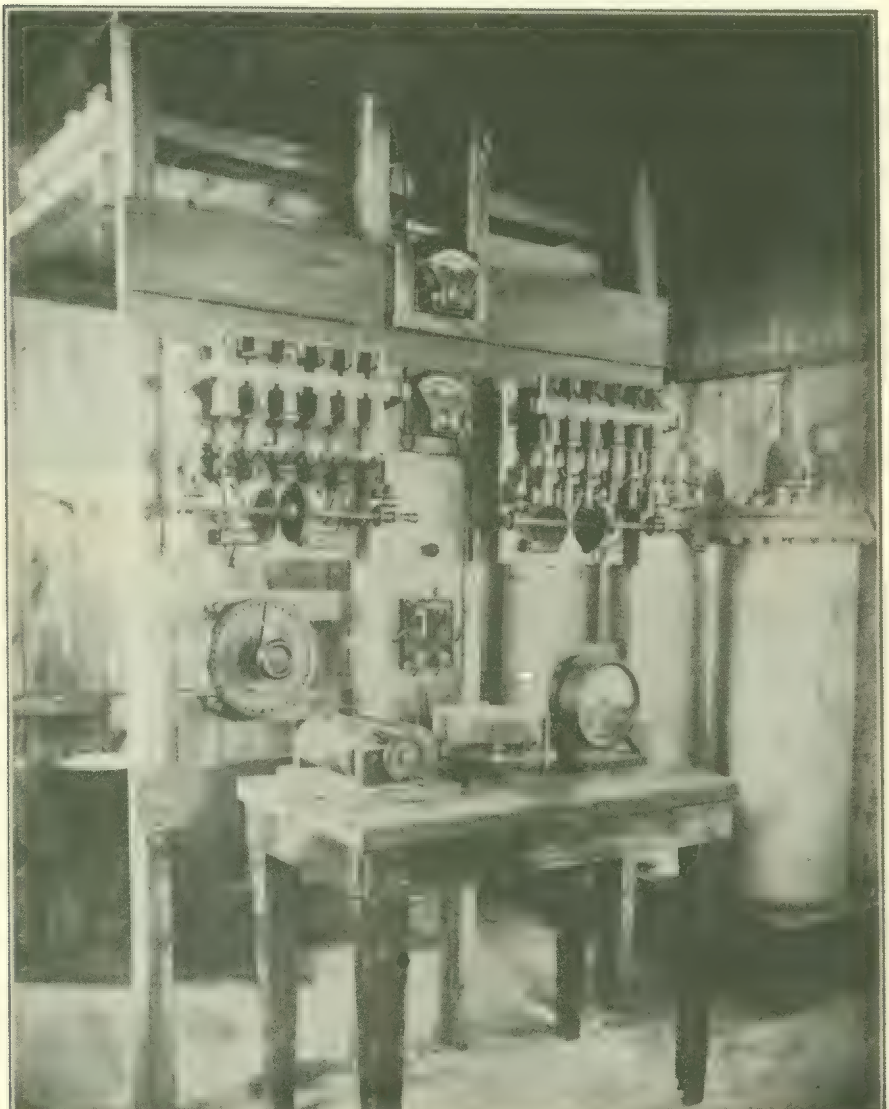

FIG. 6.

by a steam turbine connected to the steam pipe by flexible armored steam hose. The frequency is about 100,000 and the output about 3 kilowatts.

Another type, which is at present being constructed by Mr.

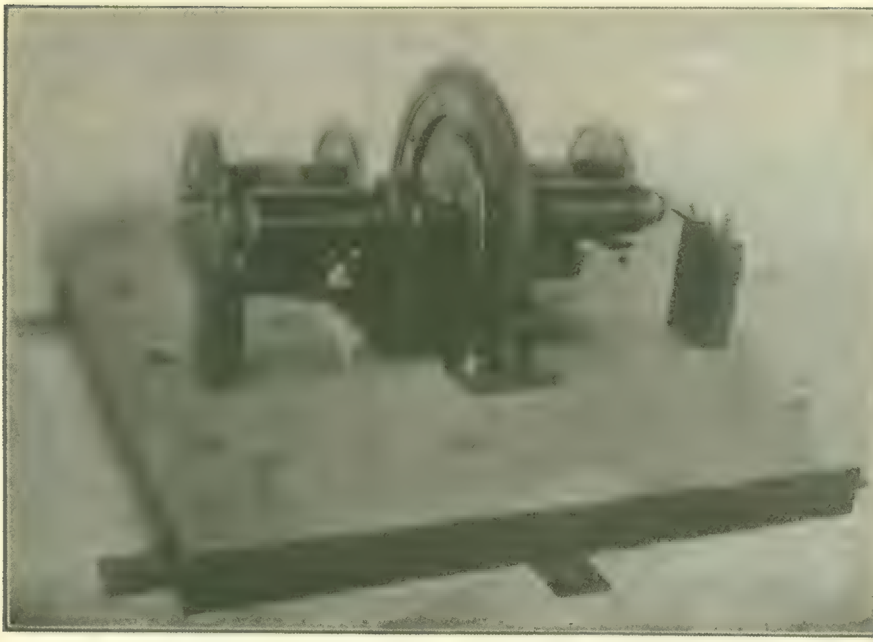

FIG. 7.

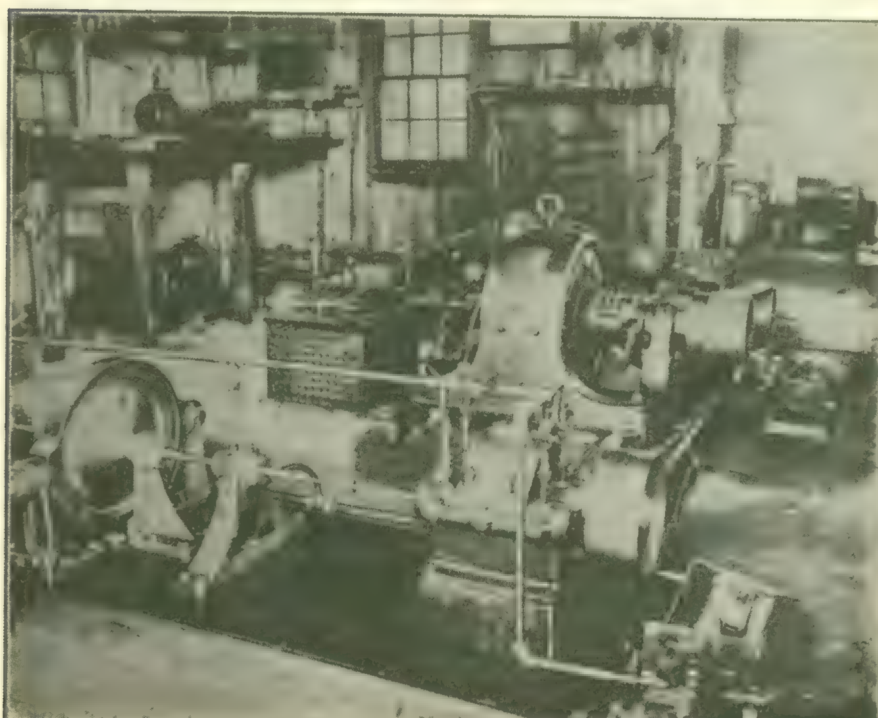

FIG. 8.

Alexanderson, to whose efforts the success of this type of generator is largely due, is designed to have an output of 10 kilowatts. Designs have been made for a generator of still larger size with a calculated output of 50 kilowatts and a frequency of 50,000. This machine is intended for Translantic work.

For some of these machines, instead of driving by gear or steam turbine, a special two-cycle motor has been devised, to operate at a frequency of 500 cycles per second.

The high frequency alternator method is believed to possess a number of advantages over other methods, inasmuch as it is set in operation by merely opening a steam valve and has no complicated electrical apparatus or circuits of any kind. The speed is regulated by the steam pressure, this being accomplished by an electrically operated reducing valve.

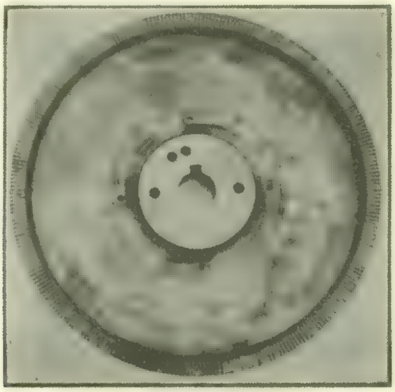

FIG. 9.

For measuring the frequency various speed indicators have been tried, but it has been found that the best way is to use a resonant circuit with an ammeter shown in Fig. D in it,[1] this being an extremely sensitive means of indicating the frequency and in addition affording a means of automatically keeping the speed constant to a small fraction of a per cent. The reducing valve is adjusted so that if left to itself the machine will run slightly above speed. As soon as it reaches one-tenth of one per cent. higher than its designed speed the resonance begins to fall and a contact is opened which slightly throttles the steam. In this way the frequency is kept varying between the limits of one-tenth of one per cent. above speed and one-tenth

1. *Electrical World and Engineer*, Nov. 11, 1899.

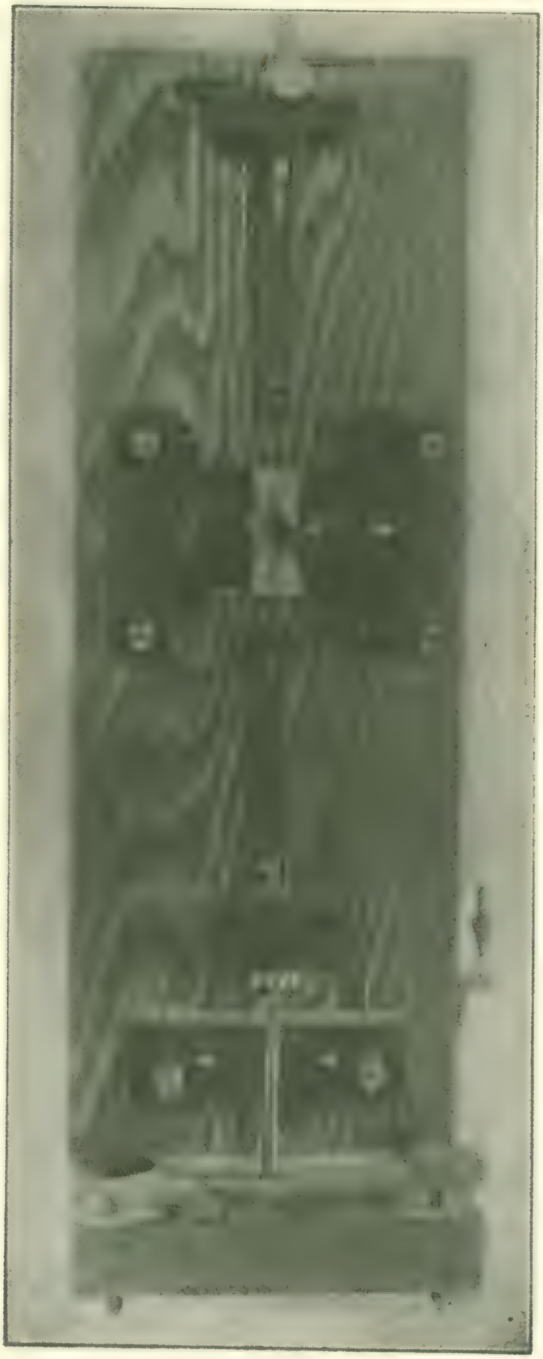

Fig. D.

of one per cent. below speed. Where the drive is electric instead of by turbine, a storage battery is used to drive the two-phase generator and even better results may be obtained as regards regulation than with steam.

2. *Transmitters.* The types of transmitters most commonly used are the carbon transmitter and static transmitter, and the carbon transmitter relay.

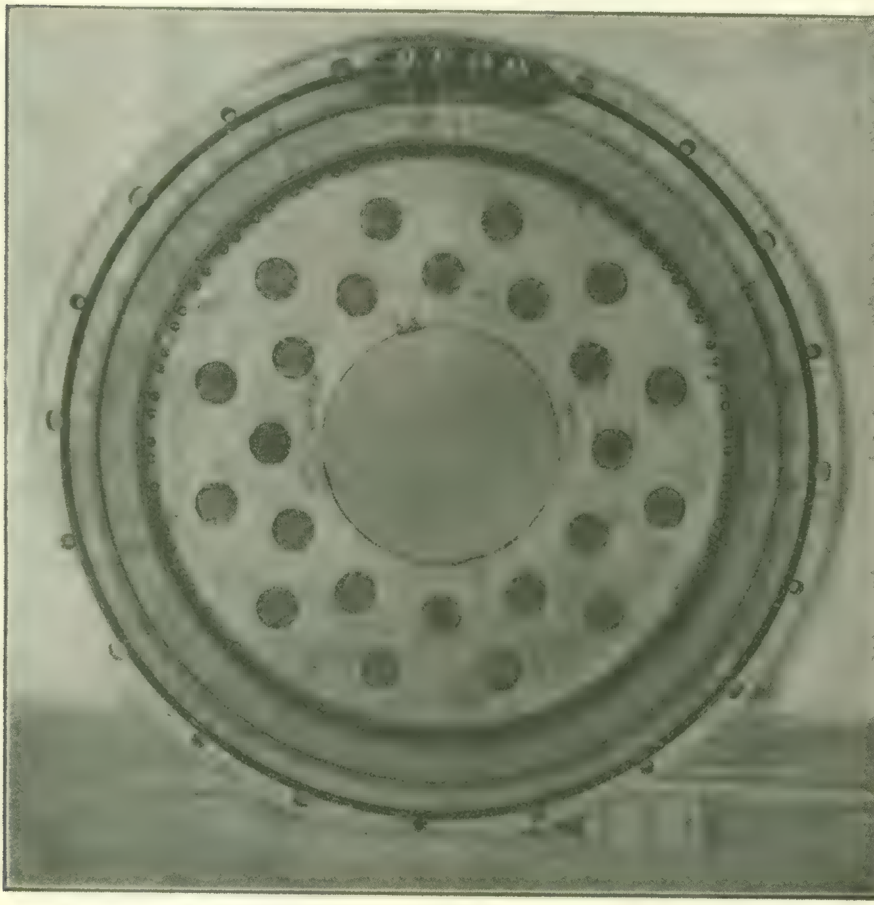

FIG. 10.

Fig. 12 shows the standard type of carbon transmitter.

It was found that the ordinary carbon transmitter was unsuited for wireless telephonic work on account of its inability to handle large amounts of power. A new type of transmitter was therefore designed which the writer has called the " trough " transmitter. It consists of a soapstone annulus to which are clamped two plates with platinum iridium electrodes. Through

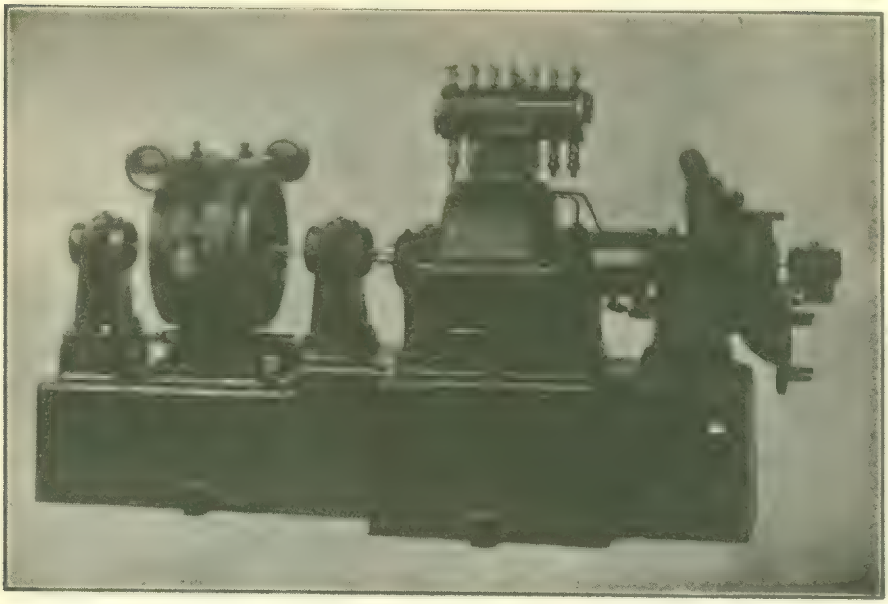

Fig. 11.

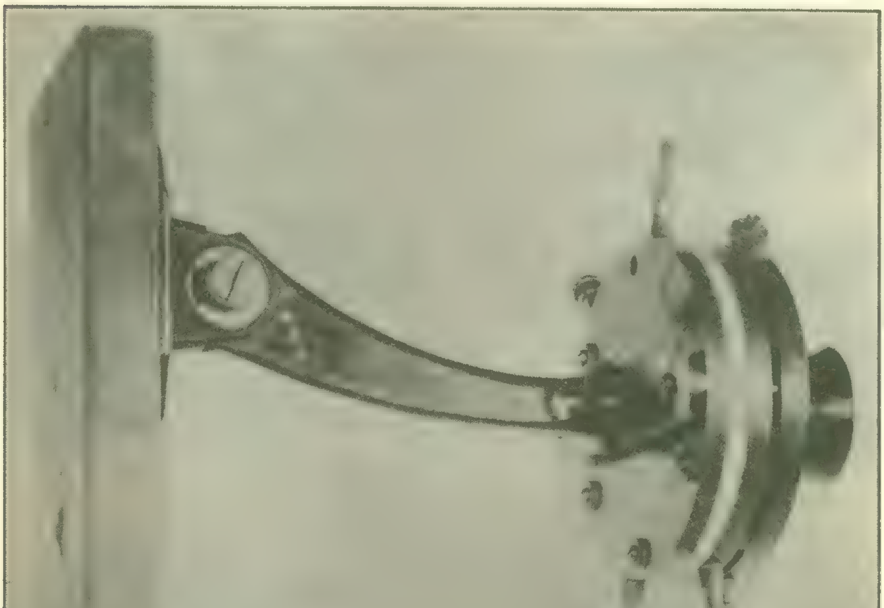

Fig. 12.

a hole in the center of one plate passes a rod, attached at one end to a diaphragm and at the other to a platinum iridium spade. The two outside electrodes are water-jacketed.

This transmitter requires no adjusting. All that is necessary is to place a teaspoonful of carbon granules in the central space. It is able to carry as much as 15 amperes continuously without the articulation falling off appreciably. It has the advantage

FIG .13.

that it never packs. The reason for this appears to be that when the carbon on one side heats and expands the electrode is pushed over against the carbon on the other side. These transmitters have handled amounts of energy up to one-half horse power, and under these circumstances give remarkably clear and perfect articulation and may be left in circuit for hours at a time. **Fig. 13 shows a modified form with split back.**

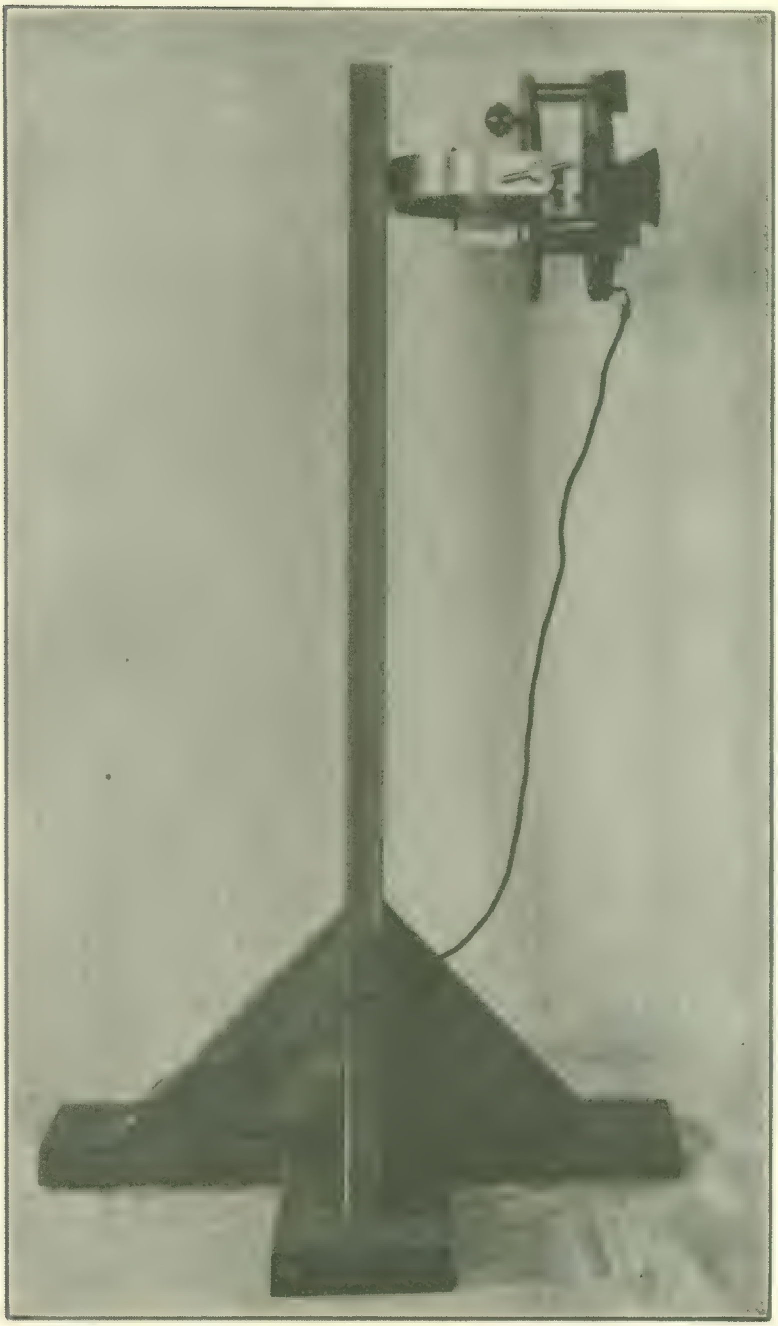

Fig. 14.

Fig. 14 shows a type of condenser transmitter in which the vibration of the diaphragm alters the electrical capacity of the transmitter, thus throwing the circuit in and out of tune or spilling more or less energy through a leakage circuit.

Fig. 15 shows a transmitting relay for strong currents. The only thing noticeable about this is that the telephone magnet is a differential one.

Fig. 16 shows another type of transmitting relay, for amplifying very feeble currents. It will readily be understood that where a person in Albany, for example, wishes to talk to another

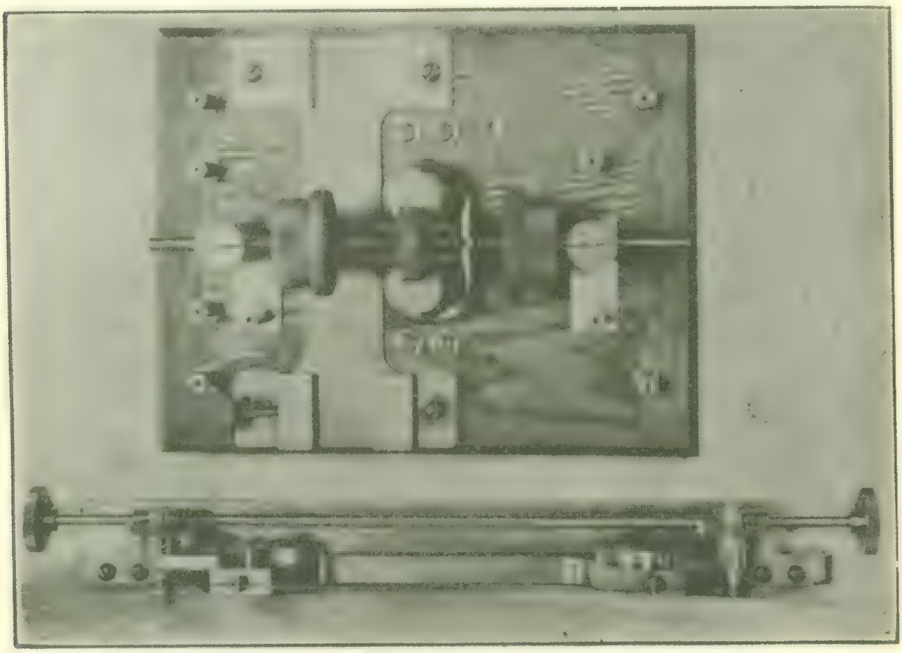

Fig. 15.

person on board a ship off New York, the wireless station being located near New York, the volume of the transmission received at New York will not be very strong, and while it may be possible to transmit it without amplification, amplification is advisable.

This receiver is a combination of the differential magnetic relay and the trough transmitter. An amplification of fifteen times can be obtained without loss of distinctness. The side electrodes of the trough are water-jacketed. The successful amplification depends upon the use of strong forces and upon keeping the moment of inertia of the moving parts as small as

possible. Amplification may also be obtained by mechanical means but as a rule this method introduces scratching noises which are very objectionable even though comparatively faint.

Other types of transmitters have also been used, such as liquid jet transmitters, Fig. 17 transmitters operating by closing the air-gap in a magnetic circuit, and so changing the inductance of the oscillating circuit, etc.

Fig. E shows a loud-speaking telephone receiver. A small iron disk is placed opposite a nozzle through which air at high

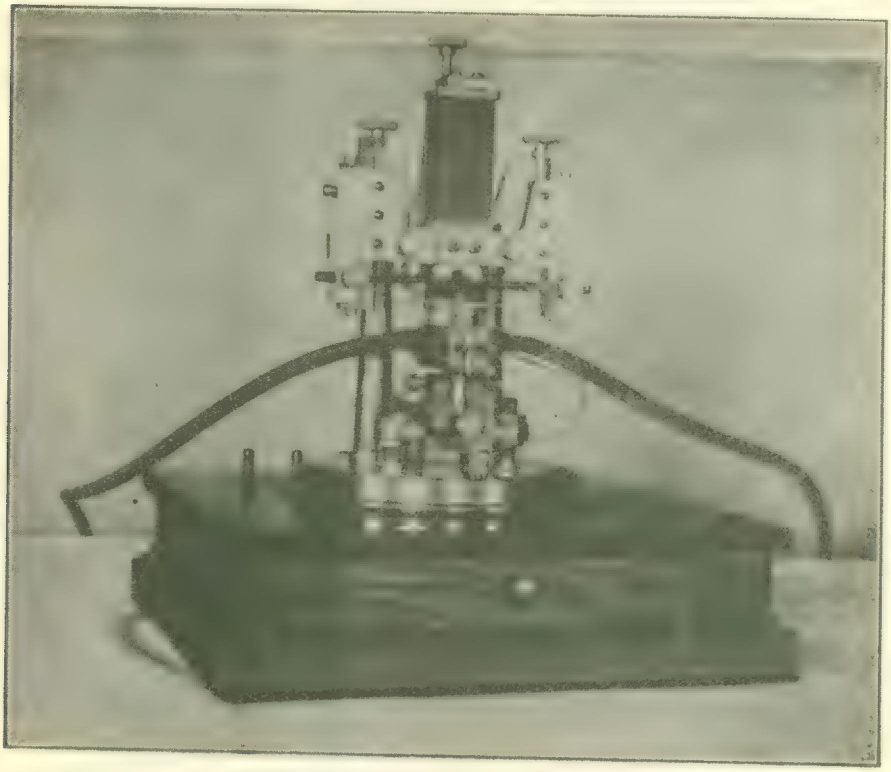

FIG. 16.

pressure is blown. As is well known, this causes the disk to be held close to the nozzle. The telephone magnets alter the position of the disk and thus produce very loud talking.

The transmitting relays are connected in the wire line circuit in the same way as the regular telephone relay, except that in place of being inserted in the middle of the line they are placed in the wireless station and an artificial line is used for balancing. There is no difficulty met with on the wireless side of the apparatus, but on the wire line side there are the well-known difficulties

due to unbalancing which have not yet been entirely overcome. For the correction of these difficulties, therefore, we must look to the engineers of the wire telephone companies. At present

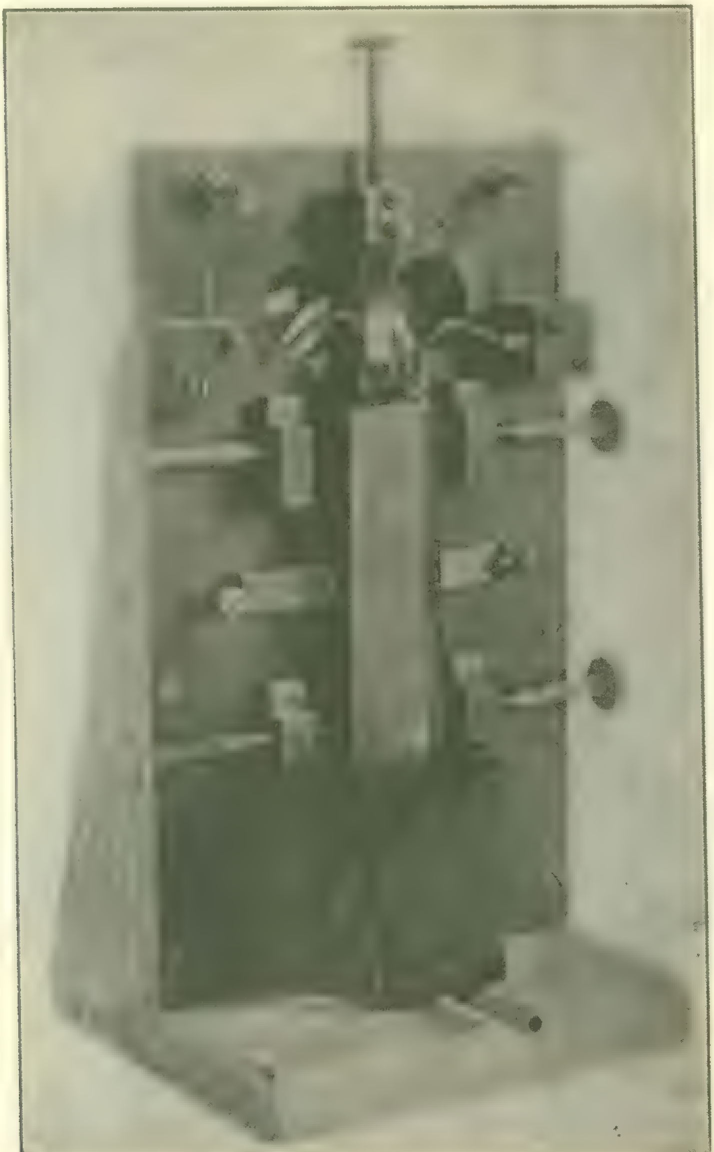

FIG. 17.

the difficulties are if anything less than those met with in relaying on wire lines alone.

3. *Transmitting circuits.* Fig. 18[1] shows a type of arc circuit.

1. U. S. patents Nos. 706,742, June 6, 1902 and 730,753, April 9, 1903.

Fig. 19[1] shows a suitable type of connection for use with a high frequency alternator.

Fig. 20[2] shows a type of circuit for use with the condenser transmitter.

Fig. 21[3] shows a type of circuit in which the modulation is accomplished by changing the inductance of one of the oscillating circuits.

As a matter of fact the transmitter may be placed almost

FIG. E.

anywhere in the circuit between the arc or dynamo and the antenna, or between the arc or dynamo and ground, or in the transformer circuit, or in shunt to an inductance or capacity, the results obtained in all cases being indistinguishable. The sole criterion of success seems to be that the transmitter should be capable of handling the energy and the circuit should be

1. U. S. patent No. 706,742, June 6, 1902.
2. U. S. patent No. 706,747, Sept. 28, 1901.
3. U. S. patent No. 706,747, Sept. 28, 1901.

properly adjusted. Some success has also been attained by placing the transmitter in the field of the dynamo[5] but this method requires very careful designing of the field circuit.

4. *Receivers.* The receiver which the writer has found most satisfactory for general purposes is the liquid barretter. Fig. 22 and 23 shows this receiver. It consists of a fine platinum wire, about a ten thousandth of an inch in diameter immersed in nitric acid. Tests made with this receiver show that it responds without apparent loss of efficiency to notes as high as 5000 per second. Some very careful measurements recently made by my assistants, Messrs. Glaubitz and Stein, give the following results:

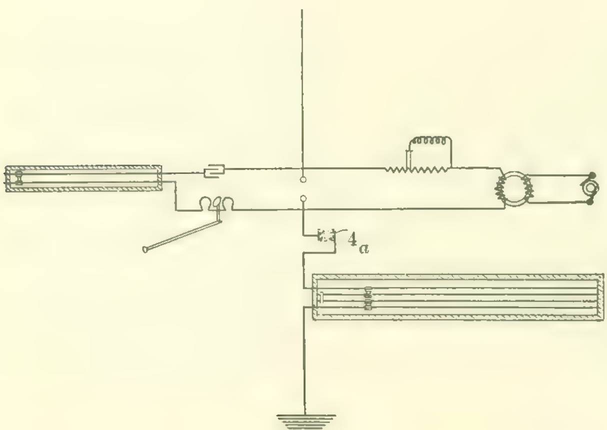

Fig.18

Fig.19

Voltage of high frequency circuit necessary to produce readable signals,	15×10^{-5} volts.
Ohmic resistance of receiver,	2,500 ohms.
Value of high frequency current necessary to produce readable signals,	6×10^{-5} amperes.
Electromagnetic wave energy required to produce audible note for period of one second,	1×10^{-4} ergs.

The telephone used for detecting the signals had a resistance of approximately 1000 ohms. Some measurements were made to determine the change of current in the telephone circuit by using a sensitive galvanometer in series with the telephone but

5. U. S. patent No. 793,649, March 30, 1905.

the results obtained were obviously too low, possibly on account of the electrostatic capacity of the turns of the galvanometer with respect to each other. It will be noted that the amount of electromagnetic wave energy necessary to produce a signal is considerably less than that given in a previous note.[1] The difference is possibly to be attributed to improvements in adjustment and operation.

The above measurements were taken by shunting the barretter across a piece of straight resistance wire in series with a hot-wire ammeter, to determine the voltage necessary, and by introducing resistance in series with the barretter to determine the resistance of the barretter. The figures were also checked in a

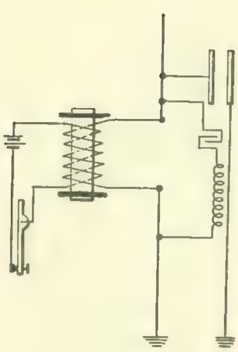

Fig.20

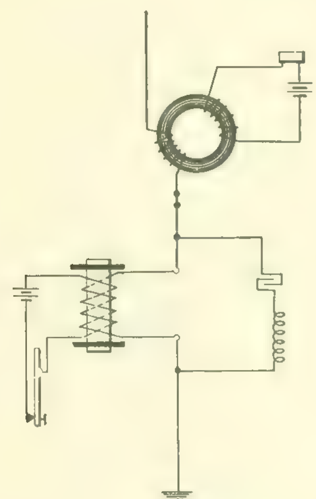

Fig.21

number of other ways and very concordant results were obtained, so that it is believed they may be relied upon.

The previously mentioned thermoelectric receivers or rectifiers of Dr. Austin and Mr. Pickard shown in Figs. 24 and 25 and the vacuum tube receivers of Fleming, deForest, and Cooper Hewitt also act very satisfactorily. The fact that the writer has not been able to get as good results from them may be due to greater familiarity with the liquid barretter and heterodyne receiver.

Figs. 26, 27, and 28 show a form of heterodyne receiver adapted for use for telephonic work.

1. *Electrical World and Engineer*, Oct. 31, 1905.

FIG. 22.

FIG. 23.

5. *Receiver connections.* Where the wireless telephone is operated by first talking into the transmitter and then throwing a switch and listening, the usual wireless telegraphic connections are used. This has been found in practice to be very incon-

FIG. 25. FIG. 24.

venient, however, and several methods have therefore been devised for talking and listening simultaneously, which methods can, of course, also be applied to duplex wireless telegraphy.

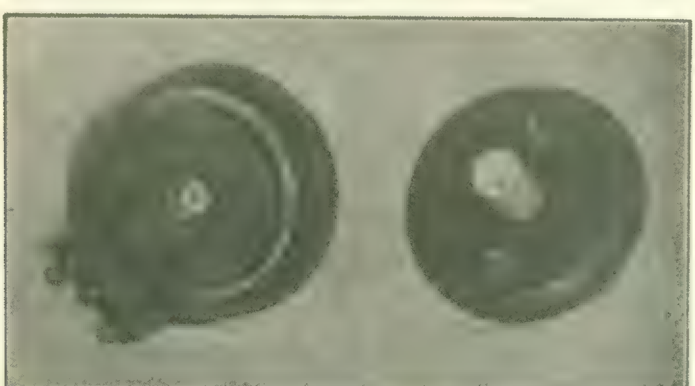

FIG. 26.

Among these methods may be mentioned the commutator method[1] and the balance method.[2]

The former method is fairly well known and consists in

1. U. S. application, 350,199, Dec. 31, 1906.
2. U. S application, 366,528, April 5, 1907.

rapidly connecting alternately the transmitter and receiver. The balance.method consists in using a phantom aerial as shown in Fig. 29, where *P* is a phantom aerial, the circuit having such

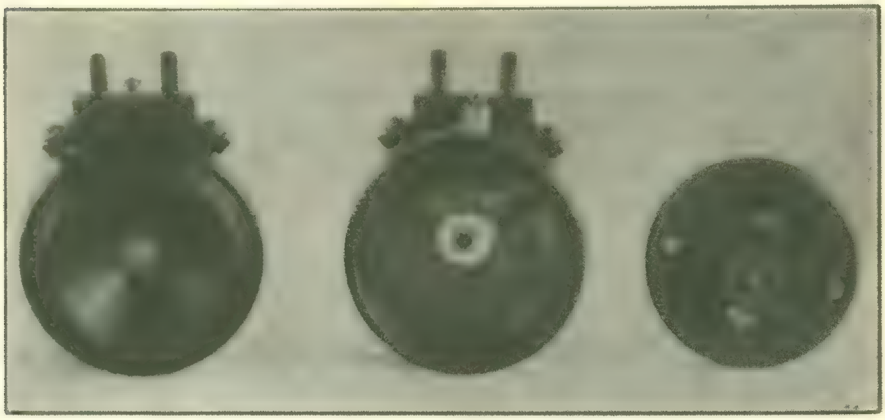

FIG. 27.

capacity inductance and resistance as to balance the radiating antenna. The apparatus is shown in Fig. H.

In order entirely to cut out disturbances in the receiver while

FIG. 28.

sending, an interference preventer, *I. P.*, the elements of which are shown in Figs. I and J, is used in the receiving circuit.

It may be here mentioned that balance methods work much

better with wireless telephony and telegraphy than with line telephony and telegraphy, for the reason that the radiation resistance of an antenna is absolutely definite and is not affected by the weather, as are line circuits. Consequently, the balance can be made very sharp and once made does not need to be altered.[1] Of course, half the energy is lost but this is a matter of practically no importance, as the cutting down of the strength of a telephonic conversation to one-half is as a rule hardly notice-

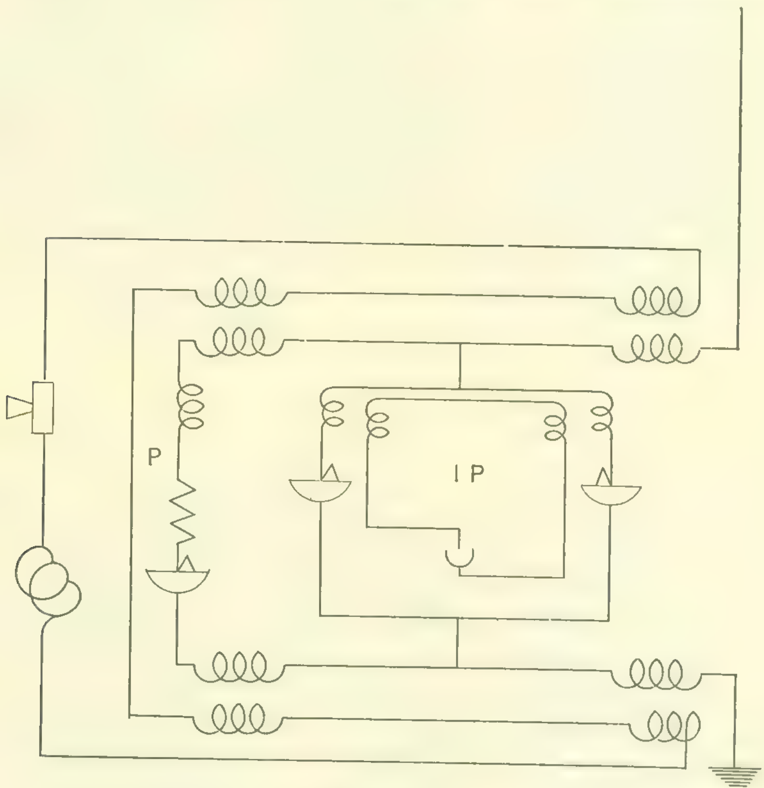

Fig. 29.

able, especially where there are no line noises or distortion of the speech through capacity effects.

1. This method may, of course, be used for duplex working in wireless telegraphy. As some question has been raised in regard to the capacity of wireless telegraph lines the writer would say that he has received messages at the rate of 250 words per minute by wireless and is now experimenting with apparatus designed to give 500 words per minute. With duplexing this gives 1,000 words per minute or 60,000 words per hour. The manager of one of the largest cable companies has stated (*London Daily Mail*, Sept. 24, 1907) that all the Trans-Atlantic cables together send 24,000 words per hour. It would appear, therefore, that

6. *Receiving station relay.* The receiving station relay is similar to the transmitting relay shown in Fig. 16. The same remarks apply to its use in connection with wire lines as to the transmitting relay.

F. OPERATION

As will be realized from the above, the operation of a wireless telephone system is very simple. The operator merely throws his switch to the position for telephoning and talks into an ordinary transmitter and listens in an ordinary telephone receiver. When the duplex method is used, as is always advisable,

FIG. H.

the conversation proceeds exactly as over an ordinary telephone line. Fig. F shows a phonograph transmitting music and speech wirelessly. Fig. G shows talking by relays from a local circuit.

if capacity alone be considered a single station on each side of the Atlantic can handle more traffic than all the present cables. It should be pointed out, however, that the mere ability to handle the messages is not sufficient and that unless the wireless telegraph companies obtain land facilities equal to those at present enjoyed by the cable companies they cannot handle the traffic as efficiency, *i.e.*, cannot deliver a message from New York to an individual in London and receive a reply in the same time. Fig. K shows a Wheatstone transmitter used for the test referred to.

I believe I am correct in saying that the transmission by wireless telephone is considerably more distinct than by wire line and that the fine inflections of the voice are brought out much better. This, I presume, is due to the fact that there is

FIG. I.

no electrostatic capacity to distort the speech, as in the case of wire lines, though I think the effect is also partly due to the absence of telephone induction coils with iron cores. Possibly some of the gentlemen present have witnessed the operation of the wireless telephone transmission between Brant Rock and

FIG. J.

Plymouth and between Brant Rock and Brooklyn. If so I think they will bear me out in saying that the transmission was clearer than over wire lines.

As a rule, there is absolute silence in the wireless telephone receiver except when talking is going on, though of course the usual

noises may be heard if persons are walking across the room, etc. This makes listening in less of a strain than when talking over wire line. Even during severe atmospheric disturbances the talking is not interfered with to any noticeable extent, provided of course that an interference preventer is used.

A comparative test was made with talking between Brant Rock and Brooklyn by wireless and by wire telephony. The talking over the wire line was done from a long distance station in Brooklyn. The wireless transmission was considerably the better. The fact that the wire line included in its circuits a cable from New York to Brooklyn was of course a disadvantage, but even allowing for this, practice and theory appear to be in agreement to the effect that transmission by wireless telephony over long distances is better than by wire line.

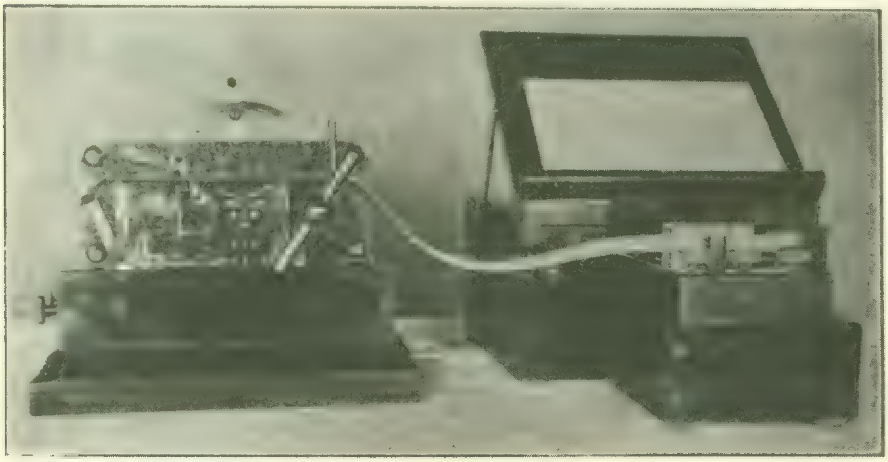

Fig. K.

This method should be of especial value to independent telephone companies, which have their local exchanges, but no long distance lines, especially since no franchises or rights of way are necessary.

G. Possibilities

A. *Local exchanges.* There is no immediate prospect that wireless telephony will take the place of local exchanges. The difficulty in regard to the number of tunes can be overcome, but the fact remains that high frequency oscillations cannot be transmitted over wire and hence each subscriber must have his own generating station. At the present time no method is known which would be practical if placed in the hands of a subscriber. If such means should be found it would be very

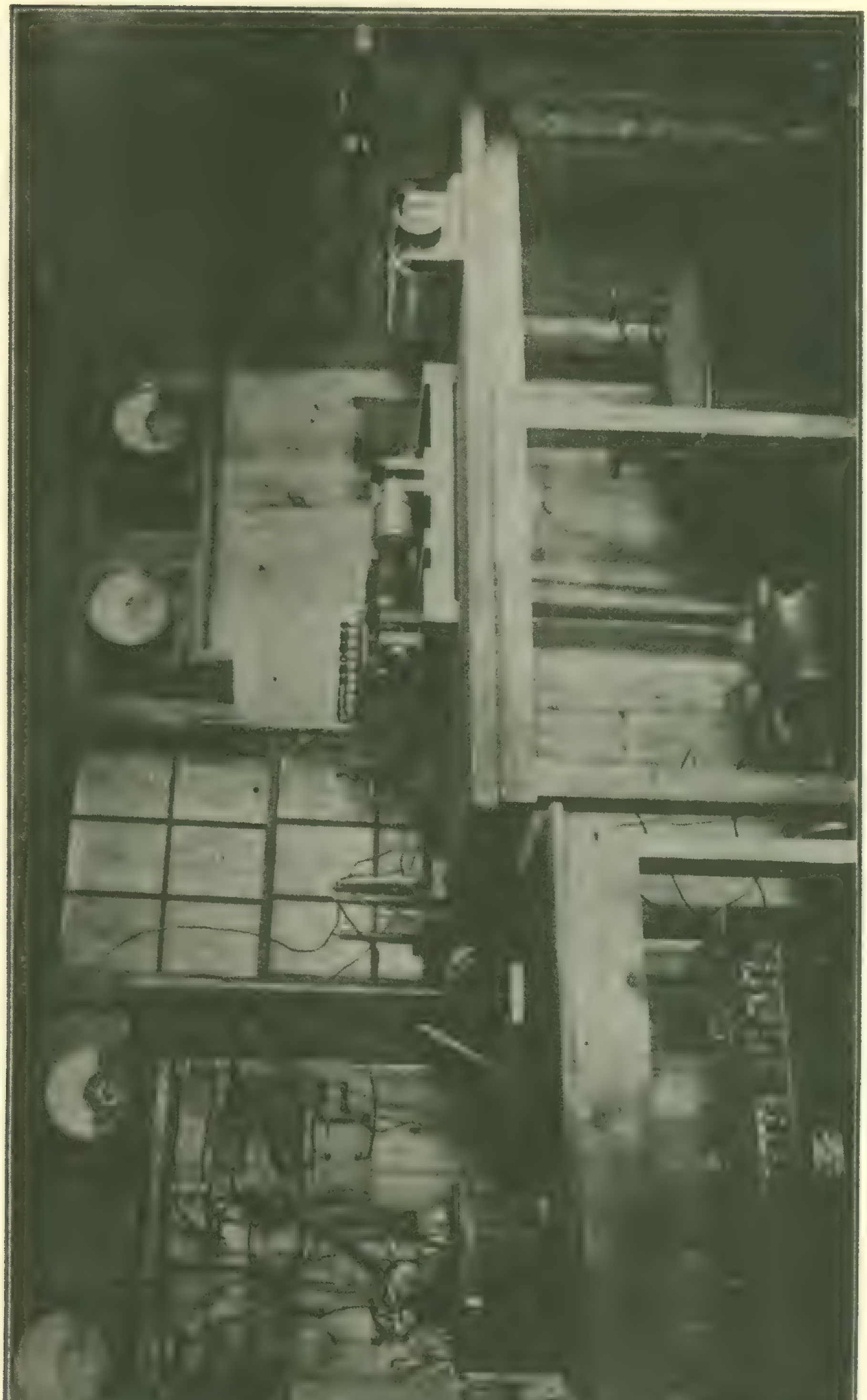

Fig. F.

convenient to call up directly instead of through an exchange, but as I see it there are no immediate prospects of this.

B. *Long-distance lines.* I believe, however, that there is a field for wireless telephony for long distance lines. The present long distance lines are very expensive to construct and to maintain, and a storm extending over any considerable section of country inflicts considerable loss on the telephone companies. Moreover, the distance of transmission is limited by the electrostatic capacity of the line, as I understand it. Wireless telephony would have the following advantages.

1. The initial cost would be very much less than that of wire lines.

Fig. G.

2. The maintenance would be practically negligible in comparison.

3. In case of any breakdown, it would be right in the station and not at some unknown point outside on the line.

4. The depreciation would be comparatively small.

5. The number of employees required would be smaller.

6. The transmission is better, and as there is no distortion of the speech, the working distance is, it is believed, considerably greater.

7. The flexibility is greater. With wire lines a telephone company may not be able to give a Boston subscriber a line to New

York, while having lines from Boston to Chicago and from Chicago to New York free. Operating wirelessly the wireless circuit normally used for operating between New York and Chicago and between Boston and Chicago could be used to operate from Boston to New York.

8. No right of way need be purchased and franchises it is believed, are not necessary.

It will be noted that I have carefully avoided mentioning any of the disadvantages of wireless telephony for long distance work. I presume this is because I am not a telephone engineer. I hope the defects will be supplied by the experts who are familiar with telephone operation and therefore better able to point out the defects. Before leaving this part of the subject I would say that I think the question of interference has been worked out to such an extent that no serious difficulty need be feared in that direction.

C. *Transmarine Transmission.* Wireless telephony is peculiarly suited for this class of work. Pupin's ingenious and beautiful method has been successful at Lake Constance, Switzerland, I believe, but even assuming that deep-sea cables of this type could be laid and operated successfully, they would nevertheless be very much more expensive than wireless telephone stations. It is believed that wireless telephony will come into extended use for this purpose. Even without further development telephonic communication could be established between Norway or Denmark or Germany or Spain and Great Britain; between Sardinia and Corsica and France and Italy; between France and Algeria, between Australia and Tasmania and New Zealand; between the United States and Cuba and Porto Rico, etc, were it not that it is at present forbidden by law.

As regards telephonic communication between England and America, my measurements show that this should be possible with an expenditure of approximately ten kilowatts and suitably large towers say 600 feet high, or with some of the new forms of antenna. Whether such a transmission would be commercially valuable or not is another matter. Personally I do not see that it would, but when I remember that at the time when the telephone was first being introduced a number of eminent business men decided that the house-to-house printing telegraph would be more of a success commercially than the telephone for the reason that no one would want to do business unless he were able to have a record of the transaction, I must admit that there is a possibility of my being mistaken in this.

D. *Wireless telephony from ship to ship.* Here, of course, wireless telephony occupies a unique position. Wireless telegraphy has the disadvantage that a telegraph operator must be carried. The additional expense is an objection in many cases. The proposition that the captain or mate should also be a telegraph operator has not met with favor. Anybody, however, can operate the wireless telephone and almost every vessel carries an engineer capable of repairing the electrical apparatus in case of accident. The final arrangement will, I believe, (if we can prevent the governments from carrying out their proposed laws, forbidding wireless telephony), be this; that passenger vessels will carry a telegraph operator and use the telephoning apparatus for ordinary work and for telegraphing where it is desired to communicate over long distances. Other vessels will use the telephone alone.

E. *Wireless telephone from ship to local exchange.* This also will, I think, have considerable value, as enabling the captain of a vessel to communicate, by relaying over the wire line, with the owner of the ship, or enabling a passenger on a vessel to communicate with friends on shore.

F. *Range of wireless telephony.* 1. *Atmospheric absorption.* The great obstacle to long distance wireless telegraphy and telephony is atmospheric absorption. For short distances up to 100 miles in the Temperate Zone there is little difference between the strength of the signals at one time of the day and another. As soon as the distance is increased much over 100 miles for the Temperate Zones and 40 or 50 miles for the Tropics the signals at night are very irregular and there is great absorption during the day time. The daylight absorption may be so great that less than a tenth of one per cent. of the energy transmitted gets through. Some nights will be as bad as day-time while on other nights there will be apparently no absorption.

Fig. 30 is a curve showing the strength of the messages transmitted between Brant Rock, Mass., and Machrihanish, Scotland, at night, during January, 1906. Nothing at all was received that month during daytime.

The change in the strength of the signals is very sudden. In working from Brant Rock to Porto Rico, a distance of 1700 miles, the strength of the signals with short wave lengths would fall off to one one-thousandth of their former value during a period of less than fifteen minutes, while the sun was rising.

Early experiments showed that the absorption was greater as the wave length was increased and the effect was at first attributed to absorption in the neighborhood of the sending station, and was thought to increase continuously with the wave length.[1] This fluctuating absorption at one time appeared to place a fundamental obstacle to commercial wireless telegraphy, as telegraph engineers will easily appreciate the impossibility of operating telegraph systems with circuits where the strength of the received signals may fall to one thousandth of its value or rise to a thousand times its value in the course of a few minutes.

It was therefore considered absolutely essential, in order to

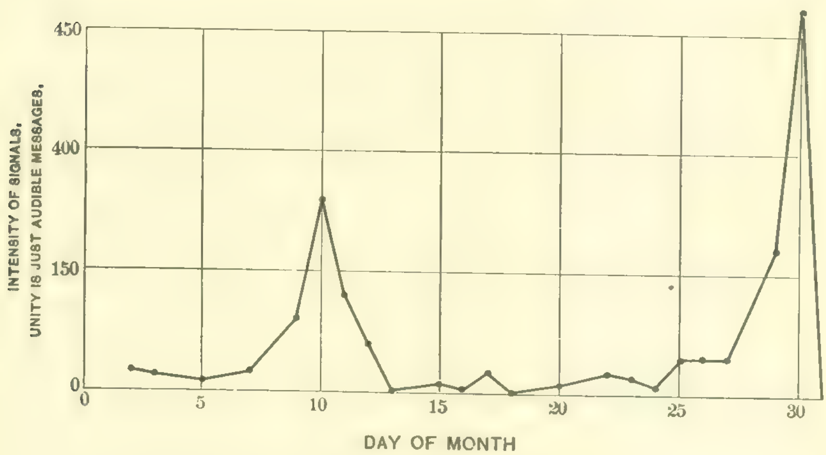

FIG. 30.—Curve showing variation of intensity of transatlantic messages for the month of January, 1906

decide whether long distance wireless telegraphy was commercially possible or not, to investigate this phenomenon fully. As a preliminary the station at Brant Rock sent to four or five other stations at varying distances and comparative readings were taken. The following table shows the general character of the results obtained:

1. A mathematical explanation of this supposed fact was given by Dr. Fleming " Principles of Electric Waves Telegraphy " pages 617–618, 1906, the following conclusions being reached:

" Accordingly, the chief part of the weakening of the wave by sunlight is done in the neighborhood of the sending antenna, where the magnetic force H is greatest, and it is more sensible for long and powerful waves than for short and feeble ones. This agrees with the observations of Mr. Marconi ".

Station	Distance	Strength of signals received on worst nights (strength of unabsorbed signals being taken as 1000).
Company's cottage........	200 yards	1000
Lynn.....................	30 miles	1000
Schenectady..............	170 miles	500
Philadelphia.............	270 miles	300
Washington...............	400 miles	150
Machrihanish.............	3000 miles	1

These experiments proved conclusively that the absorption did not take place in the neighborhood of the sending station, because the strength of the signals received at nearby stations was the same during the day as during the night while there was great variation in the strength of signals received at stations further away.

It was also found that the absorption at a given instant was a function of the direction as well as of the distance, since on a given night the signals received by stations in one direction would be greatly weakened, while there would be less weakening of the signals received by stations lying in another direction, while a few hours or a few minutes later the reverse would be the case.

This was thought to be connected with the coming weather conditions but before this fact is proved a much larger amount of data must be collected. Through the kindness of the U. S. Weather Bureau I was enabled to obtain a chart of the magnetic variations and on comparison of these with the absorption between the Massachusetts and Scotland stations there appeared to be a quite definite relation, *i.e.*, the greater the absorption the greater the magnetic variation. Here also, however, much more data is needed before arriving at a definite conclusion. The fact that the absorption did not take place in the neighborhood of the sending station having thus been definitely settled the next point to be investigated was whether or not there was any way of overcoming it.

The fact that variations in the absorption occurred with extreme rapidity, the absorption increasing sometimes a hundred fold in a single minute, and at night, when the effect could not be due to the sun directly, seemed to indicate that the body producing the absorption, whatever it was, was not in a state of continuity but was broken up into masses like clouds.[1] This

1. *Electrical Review*, May 18, 1906.

also was in accordance with some experiments made in Brazil in 1905.

From optical theories it is known that where the absorption is produced by conducting masses of a more or less definite size the absorption is to a certain extent selective. The next point in the investigation was, therefore, to determine whether there was any possibility of this being the fact in the case of the absorption of wireless signals.

Comparative tests were therefore made of the absorption at night and during the day between Brant Rock and Washington, with wave lengths varying from a fraction of a mile up to four or five miles. It was found that the absorption did not increase continuously with the wave length but reached a maximum and then fell off with great suddenness.

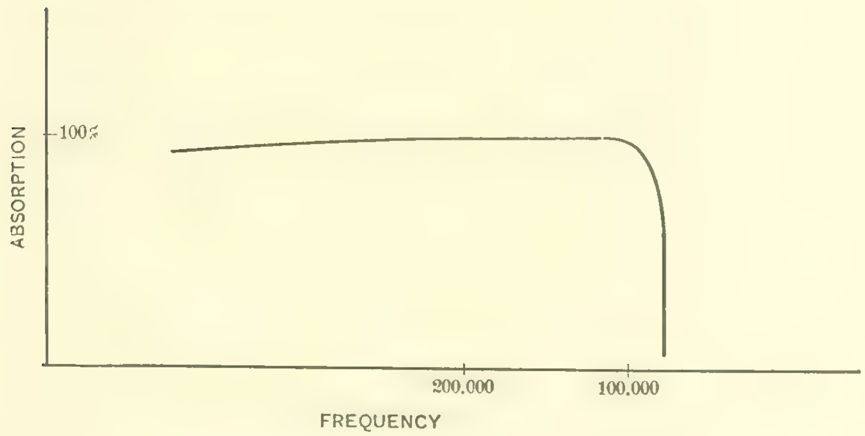

Fig.31

Fig. 31 shows the general character of the curve, the ordinates referring to the amount of the absorption and the abscissas to the wave frequency.

It may be noted that the absorption is a maximum at a frequency of about 200,000 per second, nine hundred and ninety nine thousandths (0.999) of the energy being absorbed at this frequency during daylight, while for a frequency of 50,000 the absorption does not appear to be appreciable. Longer experiments, of course, might show some absorption, but in any case it is of a different order from the absorption for the shorter wave lengths.

Experiments were then made between Brant Rock and the West Indies, a distance of 1700 miles, during the spring and

summer of 1907. It was found that the results were of the same character, *i.e.* that while there was greater absorption for frequencies of 200,000 there was comparatively little absorption for frequencies in the neighborhood of 80,000 and messages were successfully transmitted in daylight with this latter frequency. No messages were received in daylight with the higher frequency, though messages transmitted from the same station and with the same power and frequency were officially reported as having been received at Alexandria, Egypt, a distance of approximately 4000 miles.

The fact that these experiments were made during summer weather, and the receiving station was in the Tropics, and the fact that the distance, 1700 miles, was practically the same as that between Ireland and Newfoundland definitely settled the question as to whether long distance wireless telegraphy was a commercial possibility or not and the results were therefore published.[1]

Since the publication of the above results transmission has been accomplished by means of these long waves over still greater distances during daylight. Sig. Marconi early in October, 1907, succeeded in operating between Glace Bay, Nova Scotia, and Clifden, Ireland a distance of more than 2000 miles, at a frequency of approximately 70,000. The same messages were received at Brant Rock, Mass., a distance of nearly 3000 miles.

Still more recently Captain Hogg of the "Glacier" has written that during the southward passage of the Pacific fleet he received messages from the station at Brant Rock, Mass., while off Cape Ste. Roque, Brazil, S. A. The frequency used for sending was approximately 80,000, and the messages were received with the very interesting and sensitive silicon receiver invented by Mr. Pickard. This distance of 3000 miles is the greatest yet achieved by wireless transmission during daylight and would indicate that with the use of suitably high towers much longer distances can be reached.

2. *Range of wireless telephony and wireless telegraphy compared.* For the same power it is possible to telegraph to a further distance than to telephone. Distinct speech depends upon the presence of harmonics of a frequency as high as 1200 per second. The amplitude of these harmonics is according to some rough experiments made by the writer only about one per cent. of the fundamental frequency. Consequently, with a per-

1. *The Electrician* (London), July 26, 1907.

fectly modulated transmitter 100 times as much energy would be necessary to telephone a given distance as to telegraph. It fortunately happens, however, that a carbon transmitter and also the circuits in which it is used, can be so constructed as not to modulate perfectly but can be arranged so as to accent the higher harmonics.

With transmitters arranged for the purpose good transmission has been obtained with thirty times the energy required to produce audible telegraphic signals. By still further modification the power required has been reduced to approximately ten times that necessary for telegraphing, curiously enough without noticeably distorting the character of the speech. There is one fact, however, which prevents the ratio from being as large practically as the instruments show, *i.e.*, speech can be satisfactorily understood with a less increase of power above a minimum audibility than telegraphic signals.

The amount of power necessary for wireless telephony may therefore be taken as approximately five to fifteen times that necessary for wireless telegraphy; *i.e.*, under the same circumstances and for the same power the wireless telegraph will carry two to four times as far. The difference in range would be very much greater also but for the curious fact that there is much less falling off with sustained oscillations than with intermittent groups of waves, even though the frequencies are identical.

This fact has been repeatedly determined by sending between Brant Rock and Brooklyn on the same frequency, using in the one case spark produced trains of waves and in the other the high frequency dynamo. The difference in the falling off for the same frequency and energy is very great but further work is necessary before anything very definite can be said about it or the reasons finally determined.

H. How Wireless Telegraphy has been Throttled by Governmental Action

The question has been asked why, if wireless telegraphy can compete with wire lines and cables, it is not put into operation. This is not an unnatural question. Ninety nine individuals out of a hundred would probably consider that if an inventor had perfected a system of wireless telegraphy or telephony so that it would operate reliably over long distances and would handle messages at a fraction of the cost of the present cables and without interfering with other stations, he would immediately

pick out from an atlas half a dozen suitable points for operation, such as from France to Algiers, Italy to Egypt, Great Britain to Germany, New Zealand to Australia, Australia to Hong Kong, or Canada to Great Britain, and immediately commence commercial work, being perhaps delayed a few weeks on account of some slight formalities in connection with obtaining permits. The statement that nothing of the sort could be done would be received with incredulity, especially if it were known that the business men who would benefit by the proposed transmissions were strongly desirous of having them put into operation.

This is a very important matter, not because the crushing out of a new system of telegraphy is so very important in itself, but because the prospects are that other branches of the electrical profession may have to face the same situation in the near future and it is, therefore, advisable to show in some detail just what governmental ownership means in its relation to the progress of civilization. I will, therefore, explain fully, but as briefly as possible how commercial wireless telegraphy is hindered by governmental action.

Examination of a chart of the world immediately suggests a number of points as suitable for the installation of wireless communication. For example the following:

1.	United States	to	Cuba.
2.	" "	"	Porto Rico.
3.	" "	"	Jamaica and other West Indian Islands.
4.	" "	"	Bermuda.
5.	" "	"	Newfoundland.
6.	" "	"	Great Britain.
7.	" "	"	France.
8.	" "	"	Azores.
9.	Newfoundland	"	Great Britain.
10.	Great Britain	"	Ireland.
11.	" "	"	France.
12.	" "	"	Spain.
13.	" "	"	Germany.
14.	" "	"	Denmark.
15.	" "	"	Norway.
16.	France	"	Algiers.
17.	Italy	"	Egypt.
18.	New Zealand	"	Australia.
19.	Australia	"	Hong Kong.

The first fact to be noted is that these countries with the exception of Porto Rico are foreign countries and that in practically every one of these, Porto Rico is believed to be the only exception, there are stringent laws in force forbidding the erection of wireless stations without permits. The difficulty of obtaining these permits is shown by the fact that one wireless company within the writer's knowledge has been endeavoring for more than four years to obtain permits in the majority of the above mentioned foreign countries and has so far succeeded in obtaining only one permit and that for direct communication between the United States and Great Britain.

To take a specific illustration. In 1903 an American company was requested to install communication between Bermuda and the United States. The principal industry of Bermuda is the growing of produce of various kinds, which is exported almost entirely to the United States. The only present means of communicating is through Nova Scotia, and in winter especially, owing to the delays on the land lines, the service is often quite insufficient. Permission was asked of the Home Government by the Bermudian incorporators, but without success.

A petition was then signed by virtually every prominent business man in the islands and forwarded to the Home Government. The members of the New York Produce Exchange drew up a petition and forwarded it to the Secretary of State requesting him to use his influence in the matter. The Colonial Office stated in reply that it was favorable to the project but that the matter must be referred to other branches.

The Bermudian business men also sent several representatives to Great Britain to urge personally the granting of the permit. After a lapse of several years a definite reply was received to the effect that the permit would not be granted. The Bermudians then took up the matter through a Canadian company which sent several representatives to interview the authorities in Great Britain but without success. The Lord High Commissioner of Canada, Lord Strathcona, finally was kind enough to interest himself in the matter and personally presented the case before the British authorities. It is hoped by the Canadian company and the Bermudians that the permit will finally be granted, but this specific illustration will explain the difficulty in obtaining permits for operation.

As illustrating a different obstacle the case of Newfoundland may be taken. This is the natural point for establishing com-

munication with Great Britain and the experiments previously referred to as having been made between Massachusetts and the West Indies showed conclusively that there would be absolutely no difficulty in operating commercially and with ease over this distance. On the other hand to operate directly from America is a much more difficult proposition for the reason that, as examination of a great circle chart will show, the whole of Newfoundland and Nova Scotia lies between any point in the United States north of Hatteras, and Great Britain.

If operation in Newfoundland were not forbidden by law half a dozen wireless stations would be at once erected, and the companies would be only too glad to pay into the Newfoundland treasury the ten or twenty thousand dollars per annum to be collected if they were put on the same footing as the cable companies in order to save the cost of the longer transmission. The Newfoundland government a number of years ago granted a monopoly of wireless telegraphy to one company, which company has never erected a transatlantic station in that island. While this monopoly has been very injurious to Newfoundland, on account of the loss of revenue entailed, it has been still more so to the wireless companies and to the public at large, which otherwise would have had cheap transatlantic telegraphy several years ago.

Another very formidable obstacle is the fact that in practically all the foreign countries referred to (and in Porto Rico) land telegraphy is a government monopoly. Consequently, the wireless companies are entirely at the mercy of the government, are barred from collecting their own messages and must pay whatever tolls are fixed by the various governments. This, of course, also operates to prevent rapid service, since instead of communicating directly from Paris to London the messages would have to be sent from Paris by wire line to the French wireless station thence to the English wireless station and thence again by wire to London.

In a number of countries, the cable lines are also owned by their governments which makes them naturally averse to losing the invested capital or to permiting private companies to compete. It would be evident therefore that no matter to what perfection the art of wireless telegraphy is brought, years will elapse and the exercise of a great deal of political influence will be necessary before the public gets the advantages of the cheaper rates.

Ship communication. Here again the development of wireless working has been stifled by legislation. Vessel owners were at first rather slow to take up the matter of equipping their ships but after the system had proved its worth in several cases and some of the owners had had to pay large sums for salvage in cases where a wireless installation would have avoided the loss, its value began to be realized. It was at this point that the governments again stepped in with premature and injurious legislation. As a specific illustration, a United States company had arranged with the owners of some two hundred vessels to construct a line of stations from Maine to Texas, to operate with stations installed on the ships. The announcement was made that the administration proposed to recommend to Congress that wireless telegraphy be made a government monopoly.

A representative of the wireless company requested permission to submit some evidence to the effect that such a government monopoly was not necessary and that the various stations could operate without interference. A reply was received from the Administration that "information in regard to the subject was not desired", and the administration recommended that wireless communication with ships should be made a government monopoly.[1]

It was proposed to carry this out as follows:

1. To establish Navy wireless stations at points along the coast where wireless stations were needed by the merchant marine.[2-4]

2. To forbid the operation of private stations at these points.[4]

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1. Recommendations of the Inter-departmental Board on Wireless Telegraph, 1904 submitted and approved by the Administration.

2. *Ibid.* "That the maintenance of a complete coastwise system of wireless telegraphy by the Navy Department is necessary for an efficient and economical management of the fleets of the United States in time of peace and their efficient maneuvering in time of war."

3. *Ibid.* "As fast as the naval wireless telegraph stations are in operation the Navy Department shall receive and transmit through these stations free of charge all wireless messages to and from ships, providing such stations do not come in competition with commercial stations, until such time as Congress may enact the necessary legislation governing this subject". That the statement in regard to competition is disingenuous will be seen from examining the following extra Note 4, since only one station, and that a Navy one would be permitted at points where there was merchant marine business.

4. *Ibid.* "In asking for legislation on this point the board invites attention to the fact that where wireless stations are needed for the merchant marine, as a rule, the navy will also require them. The board believes it to be in the interest not only of governmental but of public

3. The Navy stations are to handle all messages to and from ships free of charge.

4. Wireless companies to be permitted, after obtaining a license from the Department of Commerce and Labor, to erect stations at points where there was no merchant marine business.[5]

The official approval and transmission of these recommendations by the Administration, although they were opposed and never went into effect, terminated, of course, all negotiations with vessel owners, since the owners would naturally not agree to contract for the transmission of their messages with the immediate prospect in view that the Government would transmit them free of charge. At the present time the masts ordered for the proposed line of stations are rotting at various points along the seaboard and the apparatus purchased for installation is deteriorating in storage.

The development of ship communication had just begun to recover from this blow when an International Wireless Telegraph Conference was arranged for by the various governments. In America no opportunity was afforded the wireless companies of presenting the case to the delegates to the Conference, and a very stringent set of regulations was adopted. The Administration transmitted these regulations to the Senate.[6] The ratification of the treaty embodying these regulations was opposed by the Marconi Co., and by the National Electric Signaling Co. The following facts were pointed out:

1. That the proposed regulations virtually amounted to confiscation of the property of the wireless companies; that the working at present was carried on at a loss; that no wireless company was at the present time paying dividends; that the proposed rates would not permit of any return on the capital invested; and that the regulations would so limit the amount of business which it would be possible to transact that it would not pay to keep up the stations.

2. That the inventors in the art of wireless telegraphy had

economy and efficiency to permit the naval stations to handle the public service, for in the present state of the art but one station is desirable for the public interest in such places. It is admitted that there may be special cases where private stations can serve a useful purpose and the board believes that the Department of Commerce and Labor should have the duty of issuing licenses in such cases under such regulations as will prevent interference with stations necessary to the national defence."

5. *Ibid.*

6. Senate Document, Sixtieth Congress, first session.

expended large sums of money in developing their systems, and such confiscation was therefore unjust and was thought to be unconstitutional.

3. That the regulations were impracticable in the following respects:

a. By requiring ships to use two tunes only[1] all stations were placed, so to speak, on two-party lines, thereby producing a maximum of interference and preventing any one station working while any other was operating.

b. Allowing only five minutes per message and assuming only ten ships each with ten messages to be in the neighborhood of a given seaport, more than eight hours would have to elapse before the last station had transmitted its message. This time is believed to be underestimated, as the regulations provide that each ship before sending its message must call the coastwise station, have a number assigned to it, inform the coast station of its distance, its true bearing in degress, its true course in degrees, its speed in nautical miles, the number of words it has to transmit; must be informed how long it will have to wait, whether the transmission is to be in alternate order or in series, interrupt the sending after each 20 words, send an interrogation mark, wait for repetition of the last word, etc.[2] Hence it would be rather difficult to maintain the average time mentioned. This excessive delay would cut down the traffic to such an extent as to render it impossible for the stations to pay expenses of maintainance, and any telegraphic engineer will appreciate the difficulty of carrying on commercial business under such regulations.

c. Placing all vessels on two-party lines introduces all the difficulties of the party line method and loses the only advantage, as it might easily happen that a ship in distress using one frequency might be within range of a number of vessels using the other frequency, but outside of range of any vessel using its own frequency. The obvious and practical method is legally to establish a single tune to be used exclusively for calling and distress signals but not for any other purpose; the transmission of messages to be continued by switching over to other tunes once the call has been received and accepted. In this way a ship in distress can always be sure of calling any vessel within range, while the transmission of messages can be carried on with-

1. Regulations II and III.
2. Regulations 19 to 26.

out interference and without one ship having to wait until the other is finished.

4. Its restrictions are of such a character as to prevent the future development of wireless telegraphy. For example.

a. The regulation[1] that all stations must carry a licensed wireless telegraph operator capable of receiving at twenty words per minute would prevent the installation of wireless stations on board the majority of ships since only the larger vessels can afford the additional expense of the operator. Many vessels would install wireless telephones which do not require a skilled telegraph operator, if it were not for this regulation.

b. The rules forbidding[2] the transmission of telegrams calling for repetition of messages, or for acknowledgement of receipt, or for telegrams to be forwarded, or for telegrams to be delivered by express or by mail, or for the transmission of money-order telegrams or for the transmission of telegrams with answer prepaid, or for the transmission of urgent telegrams are especially restrictive. By forbidding the transmission of telegrams of all the above classes the commercial field of wireless telegraphy is limited to such an extent as to deprive wireless telegraphy of its chief value.

5. It expressly forbids the use of a number of the most important developments in wireless telegraphy. For example.

a. Section 3 in effect forbids long distance transmission in daylight. This section states that ships must not use wave lengths exceeding 600 meters. It is now well known that daylight absorption is very great for these wave lengths and that much longer wave lengths must be used during daytime. This rule therefore virtually forbids wireless telegraphy during daylight except within a very limited radius, and in case of an explosion or fire on shipboard during daylight the vessel would be unable to summon assistance unless by some fortunate chance another vessel happened to be within the radius limited by the restriction to the short wave length. It also virtually prohibits ships keeping in communication with the shore for more than twelve hours out of twenty-four.

b. Section 3 states that the system employed must be a syntonized system, thus forbidding the use of systems such as the heterodyne system which do not depend for selectivity on syntony. This would not be so injurious if it were not for the

1. Section 6, paragraph III.
2. Section XXXIII.

fact that the present indications are that syntony will in the near future be abandoned as a means of obtaining selectivity.

c. The rules of Section 2, 3, and 18 to 26, virtually forbid the use of duplex and multiplex systems. There is no reason why a number of ships should not communicate with the same station simultaneously, but the above rules forbid this by requiring only two wave lengths to be used and the messages to be taken one after the other.

d. It is premature. The expression " that an art " is in its infancy is a very hackneyed one but if it can be applied properly to any art it is to wireless telegraphy. The fact that the proposed regulations are unsuitable does not reflect in any way on the ability or conscientiousness of the delegates, though it would seem that it would have been advisable to consult the engineers of the various wireless telegraph companies before drafting the rules. The main difficulty, however, is that no one, no matter what his knowledge of the present state of the art, can foresee the future developments. The question of wave length and daylight absorption is an illustration of this, as is also the question of syntonized circuits. The time has not yet come for any such hard and fixed regulations as thus proposed.

6. It was also pointed out that the public had no rights in regard to wireless telegraphy, since a patent differs from a franchise in that when the public grants a franchise it gives a right in respect to something which already exists and which it owns, and it therefore has a right to make what stipulation it chooses. In the case of a patent, however, the right is not given in respect to something which the public owns, but in regard to a new creation which exists merely in the mind of the inventor, to be called into being or not at the inventor's will, and therefore a thing in which the public has no right except as it obtains one by stipulation with the inventor. In the case of wireless telegraphy the companies invested their money under the patent law contracts with the various governments, and therefore the inforcement of regulations of the character proposed without the consent of the inventors is a breach of contract.

As a result of the hearing and of representations supporting the position of the wireless companies made by a very eminent electrical engineer the Senate Committee has decided to do nothing for the present in the matter. During the hearing the fact was brought out by the committee that the proposed regula-

tions were passed upon the assumption that interference could not be kept out, and that the U. S. Navy had already made official reports on tests of interference preventers which showed that this was not the fact. On direct question by the Senate Committee the representative of the U. S. Navy present at the hearing freely admitted that it was a fact that interference could be kept out.

Still more recently another set of recommendations has been forwarded by the Administration to the Senate endorsing the recommendation of the Secretary of the Navy that a law should be passed[1] making it an offence punishable by imprisonment for one year of a fine of $2,000 or both for a private station to continue sending when called upon to discontinue by a Navy operator, or to produce interference with a Navy station when the latter is transmitting an official message. This recommendation was not accompanied by any recommendation to the effect that the Navy stations should use any means for keeping out interference. Before the transmission of this recommendation a conference was sought with the Navy officials with a view to drafting a form of regulation which would accomplish the results sought, without placing the wireless companies at the mercy of the Government and without virtually confiscating their property but it was found impossible to obtain a hearing.[2]

The following memorandum of a portion of the interview between Secretary Straus of the Department of Commerce and Labor and the representative of the wireless company, asking for a hearing, will be of interest:

REPRESENTATIVE: " Will you not, Mr. Secretary, be willing to assist us in obtaining a treaty which, while giving the government all it desires in the way of intercommunication between different systems, reservation of wave-lengths for government purposes, etc., will, at the same time, avoid driving the wireless companies into bankruptcy? "

SECRETARY STRAUS: " The treaty was reported by the experts of the government departments, and we propose to carry it out, as it is the policy of the administration."

REPRESENTATIVE: " But, Mr. Secretary, these regulations virtually prevent the wireless companies from doing any commercial business. With everybody on one party line, even without the numerous other restrictions, it will not be possible to handle a sufficient number of messages to pay operating expenses, and the companies will necessarily be driven into bankruptcy."

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1. *Congressional Record*, Feb. 14, 1908. Also H. R. bill 17719, 60th Congress, 1st Session.

2. See also appendix.

SECRETARY STRAUS: " That has nothing to do with this department. If you are injured you should go to the Congress and ask them to reimburse you."

REPRESENTATIVE: " Mr. Secretary, you know that it would be practically impossible to get a bill to reimburse a private company through the Congress. Why should the government crush out a new and important method of communicating which will save the country millions of dollars yearly, when the government will gain nothing by the action. We feel that your department ought to assist us in this matter."

SECRETARY STRAUS: " It has been decided by the administration that the treaty should be approved as it stands."

It will be noted that this conversation took place in the United States, and not in Russia, as might possibly be otherwise inferred. It will appear from this and the experience of others that the original object of the formation of the different government departments has been rather lost sight of in recent years.

It will perhaps be seen that the difficulties in the development of wireless telegraphy have not been wholly of a technical nature and more patience may perhaps in the future be extended to those engaged in the work.

CONSIDERATIONS

The subject is, however, one which is bound to concern in the near future other branches of the engineering profession than those now affected and the present appears to be a suitable time for considering the matter more broadly.

Whatever the ultimate object of man's existence may be it is tolerably certain that it is not to occupy his entire mental activity with the question of how many grubs he can secure for food and where he can find a suitable hollow tree in which to spend the night. But whatever we have above this is due solely to the inventor (in which term I include not only the men who discovered how to produce fire and to build houses and steam engines and alternating current motors, and therefore all engineers whether they take out patents or not, but also those who discover how to distribute what is created in such a way as to make it available).

In the state of nature which Tolstoy so greatly lauds and so carefully avoids advance is impossible; all available energy of mind and body is necessarily employed in the problem of maintaining a bare existence. Before we can advance toward our goal, whatever it is, we must first have time and opportunity and

a means of maintaining any advance. That we have this time and opportunity is due to the fact that by means of innumerable inventions we are rendered every day less dependent upon the accidents of nature. It would therefore appear, that whatever our ultimate goal may be, the first essential for reaching it is an increased control over the forces of nature.

This increased control can only be obtained through intense effort. When we see a performer at a circus contorting his body into apparently impossible positions we realize the peculiar aptitude and the many years of training which must have been necessary. It is not generally realized, however, that a still more peculiar aptitude and many more years of still more intense training are necessary for those who would do useful work in any branch of mental achievement. We seldom think, in reading a mathematical paper for example, that the author has studied possibly for an average of ten or twelve hours a day for twenty or forty years before achieving sufficient proficiency in his subject to be able to accomplish the work.

To obtain results in a special line therefore a man with special aptitude and training is required. In addition to this there must be the opportunity. Hundreds of thousands, and in many cases millions of dollars are necessary for the development of an important invention. Such sums will not be furnished if there is no prospect of a return. As the success of an invention is always doubtful, the return from a successful invention must be sufficient to cover the losses from the much larger number of failures, for if the average return from one hundred inventions falls below that obtainable from mortgages or other forms of secure investment there will be no incentive.

The following question seem to me to be worthy of consideration:

1. Whether public officials, elected by the people, would consider themselves justified in expending millions of dollars on the development of inventions the success of which was uncertain.

2. Whether the best men to develop such inventions successfully would be found among the Government officials available.

3. Whether development can be expected in an art or industry entirely under Government control or ownership.

4. Whether universal Government control or ownership does not necessarily involve a fixed and non-progressive state as opposed to a state of progress and development.

Appendix

In the United States some additional hindrances on the part of the Government have been met with. For example, in the United States, and in Russia, as well, an inventor has no legal remedy in case the Government appropriates his invention.[1] It might be thought that the inventor could protect himself by suing infringing companies, but this is not so.

The wireless sets originally used by the United States Navy were imported from a country which was not at that time under the Patent Convention, and as they were purchased abroad no action could be taken. The then Secretary of the Navy, Mr. Moody, refused to require the foreign company to appoint a responsible representative in America. It was not until some years later, when, Mr. Morton being Secretary and the matter having been taken up by one of the Senators, this was done, and an injunction was obtained against the representative so appointed.

On further protest the next Secretary of the Navy, Mr. Bonaparte, stated that the patents could not be recognized as they had not been sustained. He was again approached but said that he had decided that he was not bound to respect them as he considered the price too high.[2] He declined, however, to allow the price to be fixed by arbitration, stating that he considered that the price should be fixed with reference to the cost of manufacture solely. The principal infringing companies having been enjoined the Navy and Army began manufacturing the devices themselves in quantities.

Through the influence of one of the Senators the matter was again taken up and it was arranged that the Secretary of the Navy, Mr. Bonaparte, should obtain a legal opinion from the Attorney-General in regard to the matter. This opinion was prepared by one of the Attorney-General's assistants and proved to sustain the claims of the wireless company on every point. Before it was finally transmitted the Secretary of the Navy, Mr. Bonaparte, withdrew his request for an opinion.

The wireless company received a letter[3] from the Navy Department to the effect that by order of the Administration the patents had been turned over to the Navy Department. A written request[4] was forwarded to the Administration, pointing

1. Russel *vs.* United States, decided in 1900, 182 U. S. 516.
2. Letter April 19, 1906.
3. Letter No. 137,244, July 11, 1906.
4. Letter April 3, 1907.

out that the above-mentioned property had been confiscated by the Government without a hearing and asking for a hearing. No reply was received.

The above is given as an illustration of the effect of the present law under which an inventor has no legal remedy against the confiscation of his patents by the United States Government. Among other recent instances of confiscation of inventions by the Government may be mentioned those of the Krupp and Armstrong Companies, the San Francisco Dry Dock, etc.

As the situation is not generally understood attention is here called to it. It should be remedied, as it operates very injuriously as regards the Government departments themselves. The Government is deprived of the services of American inventors who either place their talent at the disposal of other countries, as in the case of Hiram Maxim, or turn their attention to other lines. The general result is that the United States Government, instead of leading other nations, is obliged to follow after and copy, though the success of the United States Navy in developing submarine boats is an illustration of what can be accomplished in cases where the inventor has been able to develop his work without confiscation.

In 1906 President Roosevelt's attention was called to the above facts. He was asked if the administration would not introduce a bill to remedy this state of affairs. He replied that the administration had too many bills of its own to look after, but, on further inquiry, stated that if such a bill was introduced the administration would not oppose it.

On the strength of this promise a bill was introduced and unanimously reported, as follows:

House of Representatives, 60th Congress, 1st Session, Report No. 184

The Committee on Patents, to whom was referred the bill (H. R. 7653) to amend section 4919 of the Revised Statutes of the United States, to provide additional protection for owners of patents of the United States, and for other purposes, have considered the same, and recommend that the bill do pass with the following amendment:

In line 7, page 1, strike out the words " has been or," and insert the word " hereafter " after the word " shall."

A bill substantially the same as that now reported was passed by the Senate at the last Congress, and favorably reported to the House, but at too late a day in the session to receive consideration.

The object of the bill is to provide for owners of United States patents a remedy for the taking of their property by the United States for pub-

lic use, when such taking occurs without the license or authority of such owners and without compensation.

In England and in practically all over civilized countries, except Russia and the United States, the Government can not appropriate an invention without paying a fair price for it. A regular tribunal is charged with the duty of determining what is a fair price for the use of an invention appropriated by the Government in case the Government considers the inventor's charge to be excessive. The United States habitually appropriates at its pleasure the patented inventions of its citizens and declines payment therefor. And this notwithstanding the fact that according to the decisions of the Supreme Court a patent of the United States is property within the meaning of the term as used in the Constitution and laws of the United States, and the use of a patented invention by the Government is a taking of private property, which can not be done lawfully without compensation to the owners. (Solomons *v.* United States, 137 U. S., 342, 346; McKeever *v.* United States, 14 Ct. Cls., R., 396; Affirmed S. C. 18 Ct. Cls., R., 745.)

But notwithstanding this right to protection which patentees and other property owners derive from Article V of the Amendments to the Constitution, it has been held by the Supreme Court that the owner of a patent can not restrain its infringement by the United States or an officer or agent of the Government. (Schillinger *v.* United States, 155 U. S., 163 (1894); Russell *v.* United States, 182 U. S., 516 (1900).)

In both of these cases the court held that in the absence of an express contract between the Government and the patentee, or transactions between them from which a contract may be implied, no court of the United States is vested with jurisdiction to entertain a suit or action by a patentee seeking to recover compensation for the use of his invention by the Government.

How next to impossible it would be to make a case of implied contract which would render the Government liable under the court's decision may be inferred from the following statement of the facts appearing in the Russell case just cited. It there appeared that at the Government's invitation Russell exhibited his patented invention to a board of officers appointed by the Secretary of War. The Government announced that it would adopt and use a device embodying his invention. Prior to the adoption and use of the device Russell communicated his patent to the War Department, showing that his patent covered the device and tended the use of his invention to the Government for reasonable compensation. The Government proceeded to use the device without denying Russell's right to compensation, but with the remark that he should seek his remedy by some means other than Executive action. And the Russell case is only a sample case; one of many.

It seems to be necessary and proper to provide for patentees a remedy, such as the passage of this bill will secure, for the invasion of their rights. Without such remedy, patentees are the only persons who are outside the protection of Article V of the Amendments of the Constitution. "Nor shall private property be taken for public use without just compensation."

Without such remedy a patent is not what it purports to be on its

face. Many inventors have spent years of their lives and practically bankrupted themselves in developing inventions primarily of use to the Government, only to find in the end, after their property has been seized by the Government, that they have no legal means of redress, and that the governmental Departments will not recognize the decisions of the courts.

Without such remedy there is a ridiculous discrimination between inventors. The inventor of a children's game or of a new brand of chewing gum is protected by the courts. But the inventor of a device which may save the nation from an humiliating defeat in time of war, or reduce the cost of carrying the mails, or reduce the number of shipwrecks on the coast, is afforded no protection; the governmental Departments have the power to confiscate his property and habitually exercise that power. It may be a new type of breech mechanism, or a dry dock, or a method of communicating with ships at sea; if the invention is valuable the Government can and does seize it, though the inventor may have spent years of his life and bankrupted himself and his friends in developing it.

It may be conceded that the Government ought to have the right to appropriate any invention necessary or convenient for natural defense or for beneficent public use, and that, too, without previous arrangement or negotiation with the owner. Nevertheless, the appropriation having been made it would seem that justice to the citizen demands that in due time he should receive fair compensation for his property.

The claim is made by some that the Government, being the grantor of the patent, ought to have the right to use without compensation such inventions as are necessary for its purposes.

One answer to this is that there is no such limitation or reservation in the law governing the granting of patents; and another answer is that if that were the law there would be no time, brains, or money spent by anyone in inventing those things for which there would be no remuneration.

But it is useless to multiply reasons to justify the passage of the bill. The one fundamental reason already assigned is unanswerable—that no American citizen's property can be appropriated for public use by the Government or by anyone else without compensation being made therefor.

The amendment proposed, by striking out the words " has been or " and the use of the word " hereafter," in line 7, page 1, is deemed advisable, that there may be no question arising upon statutory construction that the law is not retroactive in its effect, but will apply only to future appropriations of patents by the Government.

It passed the House of Representatives by a large majority, the leaders of both the Republican and Democratic parties speaking in favor of it. It passed in the Senate unanimously. It did not become a law, however, as President Roosevelt declined to sign it, though its signature was strongly recommended by Secretary Taft, Senator Knox, and others. No

reason was given by President Roosevelt for declining to sign the bill, but it is understood that his action was due to the fact that the ratification of the proposed wireless treaty had been opposed by one of those interested in the passage of this bill.

THE EVOLUTION OF ELECTRIC WAVE TELEGRAPHY

J[ohn] A[mbrose] Fleming

PART III.—ELECTRIC WAVE OR RADIO-TELEGRAPHY

CHAPTER VII

THE EVOLUTION OF ELECTRIC WAVE TELEGRAPHY

1. Early Ideas and Experiments.—The reader who desires to study the earlier attempts to conduct practical telegraphy without connecting wires must consult books more especially devoted to the historical side of the subject.[1]

From the earliest days of electric telegraphy, inventors had their attention directed to the problem of dispensing in part or entirely with continuous interconnecting wires. In 1838, Steinheil of Munich, acting on a suggestion made by Gauss, demonstrated that the earth could perform the function of a return for a telegraphic circuit, and thus made one of the most important contributions to practical telegraphy.

He seems, moreover, to have anticipated that in time improvements might be effected by which the necessity for any metallic circuit at all would be removed.[2] From the date of that suggestion the notion of telegraphy without wires may be said to have been ever present to the minds of telegraphic engineers.

The necessity for finding some solution of the problem of wireless telegraphy increased as the art of electric telegraphy itself extended, even if it were only to enable telegraphists to bridge over some short break or interval in a metallic circuit. Suffice it here to say that if we exclude the method depending on the employment of electromagnetic waves, the processes which had been previously found feasible or had been suggested were based upon—

(i.) The conduction of electric currents through the moist earth or the water of rivers, lakes, or seas. This method particularly engaged

[1] We may particularly refer the reader to the excellent work by Mr. J. J. Fahie, "A History of Wireless Telegraphy" (Blackwood & Sons, London and Edinburgh).

[2] See Fahie's "History of Wireless Telegraphy, 1838–1899," 1899, p. 4. (Blackwood & Co.); also Fahie's "History of Electric Telegraphy to the Year 1837," pp. 343–348, for the history of the *earth return* in telegraphy.

Although Stenheil was not the first to employ or suggest the use of an earth return for completing an electric circuit, he was the first to apply it in practical telegraphy, and to realize its importance.

See also Steinheil, "Ueber Telegraphie, insbesondere durch galvanische Kräfte." Munich, 1838.

Interesting quotations from Steinheil's writings are given in Mr. Fahie's book on wireless telegraphy.

the attention of Morse, Lindsay, Trowbridge, Preece, Rathenau, Strecker, Wilkins, and Melhuish.

(ii.) Electromagnetic induction between parallel metallic conductors, either complete circuits or circuits including earth returns. Suggested and studied by Trowbridge, Preece, Stevenson, and Lodge.

(iii.) A combination of methods (i.) and (ii.). Made into a practical system chiefly by the labours of Sir William Preece, aided by the British Postal Telegraph Engineers.

(iv.) Electrostatic induction between conductors separated by a greater or less distance. Brought to a working success by Edison, Gilliland, Phelps, and W. Smith, as a means of communication with moving railway trains.

The reader wishing to have some information with regard to the earlier researches of the above-named inventors may be referred to the following original papers, as well as to the "History of Wireless Telegraphy," by Mr. J. J. Fahie above mentioned.

J. Trowbridge, "The Earth as a Conductor of Electricity," *American Acad. Arts and Sciences*, 1880.

W. H. Preece, "Recent Progress in Telephony," *British Association Report*, 1882.

W. H. Preece, "Electric Induction between Wires and Wires," *British Association Reports*, 1886 and 1887.

W. H. Preece, "Electric Signalling without Wires," *Journal Soc. of Arts*, February 23, 1894.

W. H. Preece, "Signalling through Space without Wires," *Proc. Roy. Inst. Lond.*, 1897, vol. xv. p. 467.

W. H. Preece, "Ætheric Wireless Telegraphy," *Proc. Inst. Elec. Eng. Lond.*, 1898, vol. xxvii. p. 869.

O. J. Lodge, "Magnetic Space Telegraphy," *Proc. Inst. Elec. Eng.*, 1899, vol. xxvii. p. 799.

In many cases suggestions were put forward which were based upon obviously erroneous ideas, and even embodied in patent specifications without being subjected to critical trial. Nevertheless, the best of the methods above classified had only enabled comparatively short distances to be covered. Even the most effective of them, viz. the method involving both conduction through the soil or water and electromagnetic induction between parallel wires, was extremely limited in its applicability by reason of the necessity for employing two parallel metallic wire circuits almost as long as the distance to be bridged.

A new era dawned when the scientific investigations commenced which finally placed us in possession of the principal facts connected with the generation and detection of electromagnetic waves, or as they are more shortly called, electric waves.

Maxwell's profound speculations and mathematical researches resulted, as we have seen, in the enunciation in 1865 of his famous electromagnetic theory of light. This theory, owing to its abstract nature, was not at first fully appreciated. Hertz's discoveries and investigations, published in 1888, cast a flood of light upon its meaning, and whilst opening up a wide and promising field for experimental investigation, gave such enforcement to Maxwell's theory that it at once commanded general attention.

The matter, however, which chiefly interested physicists were the

properties of the long waves generated in the æther by Hertzian methods, and the similarity between the effects connected with them and familiar optical phenomena. Hence a rapidly accumulated mass of experimental evidence was obtained, tending to show that luminous radiation is electromagnetic in nature. These electro-optic phenomena were sedulously studied, and physical optics became, as it were, a department of electromagnetism.

When any new field of discovery or invention is thus laid open, it invites the attention of two classes of minds. There are those who are chiefly drawn to its cultivation by a desire to increase purely scientific knowledge, and to explore the mysteries involved, regardless of any particular practical utility they may possess. On the other hand, there are others to whom this pursuit of novel facts or effects, or the unravelling of complicated phenomena, or the construction of new theories, does not appeal. They are impelled to look at once for applications of the new knowledge which will minister to the convenience or mitigate the troubles of mankind. Probably in neither case is a more personal motive entirely absent, but whilst some minds regard the discovery of new physical facts or laws as an end in itself, others regard them only as a means to an end, and invent rather than discover or explore. The general non-scientific public are, however, prone to attach more importance to the so-called applications than to the discoveries out of which they have grown. Hence the practical inventor or applier of scientific knowledge generally occupies in the public mind a more prominent position than the purely scientific investigator. Unless the latter has the good fortune to make some sensational discovery capable of immediate technical application, such as the Röntgen radiation, his work will seldom attract notice outside of a limited circle of experts. So it was in the case of the field of investigation laid open by Hertz. Between 1888 and 1895 a host of scientific workers in various lands gathered in a rich harvest of scientific knowledge concerning the properties and powers of electromagnetic waves. The non-scientific public concerned itself but little with these results.

In 1892 Nikola Tesla captured the attention of the whole scientific world by his fascinating experiments on high frequency electric currents. He stimulated the scientific imagination of others as well as displayed his own, and created a widespread interest in his brilliant demonstrations.

Amongst those who witnessed these things no one was more able to appreciate their inner meaning than Sir William Crookes. More than twenty years previously he had explored with wonderful skill and insight the phenomena of electrical discharge in high vacua, and had produced the instrument which subsequently produced the Röntgen rays. He allowed a trained scientific imagination to busy itself with the recent discoveries, and he wrote a now well-known article "On some Possibilities of Electricity" in the *Fortnightly Review* for February, 1892 (p. 173), in which he endeavoured to forecast some of the applications of high frequency electric currents and of Hertzian waves.

In this outlook into the future he clearly discerned the coming of a new form of wireless telegraphy based on an application of Hertz's

discoveries to the communication of intelligence from place to place. In the course of the paper Sir William Crookes made a cryptic reference to experiments in this direction he had witnessed "some years ago," which were subsequently explained to refer to unpublished investigations by the late Professor D. E. Hughes, in which signals were sent "a few hundred yards," without connecting wires, by the aid of a telephone. No details of the experiments were given, or any hint of how the result was obtained. For the purposes of patent litigation this notable essay has been put forward as an anticipation of subsequent practical work. It is necessary, however, to keep clearly in mind the true meaning of "invention." Invention does not consist in displaying a few brilliant and original ideas. Neither does it consist in outlining a certain set of requirements and broadly defining the means by which certain ends may be attained. Invention consists in overcoming the practical difficulties of the new advance, not merely talking or writing about the new thing, but in *doing it*, and doing it so that those who come after have had real obstacles cleared out of their way, and have a process or appliance at their disposal which was not there before the inventor entered the field. In most cases, however, the removal of the obstacles which block the way is not entirely the work of one person. The fort is captured only after a series of attacks, each conducted under a different leader. In these cases the inventor who breaks down the last obstruction or leads the final assault is more particularly associated in the public mind with the victory than are his predecessors, though his intrinsic contribution may not be actually of greater importance.

There are other cases, however, in which, prior to the work of one man, we can find no actual achievement, although the end to be attained, and to some extent the character of the means to be used, are clearly recognized.

In the article to which reference is made we find much remarkable prognostication, but not a description of actual inventions.

It emphasized, in fact, how much at that date (1892) yet remained to be done. Speaking of electromagnetic waves and their properties, Sir William Crookes says (*loc. cit.*):—

"Here is unfolded to us a new and astonishing world, one which it is hard to conceive should contain no possibilities of transmitting and receiving intelligence.

"Rays of light will not pierce through a wall, nor, as we know only too well, through a London fog. But the electrical vibrations of a yard or more in wave length of which I have spoken will easily pierce such mediums, which to them will be transparent. Here, then, is revealed the bewildering possibility of telegraphy without wires, posts, cables, or any of our present costly appliances. Granted a few reasonable postulates, the whole thing comes well within the realms of possible fulfilment. At the present time experimentalists are able to generate electrical waves of any desired wave-length from a few feet upwards, and to keep up a succession of such waves radiating into space in all directions. It is possible, too, with some of these rays, if not with all, to refract them through suitably shaped bodies acting as lenses, and so direct a sheaf of rays in any given direction; enormous lens-shaped masses of pitch and similar bodies have been used for this purpose. Also an experimentalist at a distance can receive some, if not all, of these rays on a properly constituted instrument, and by concerted signals messages in the Morse code can thus pass from one operator to another. What, therefore, remains to be discovered is—firstly, simpler and more certain means of generating electrical rays of any desired wave-length, from the shortest, say of a few feet in length, which will easily pass through buildings and fogs, to

those long waves whose lengths are measured by tens, hundreds, and thousands of miles; secondly, more delicate receivers which will respond to wave-lengths between certain defined limits and be silent to all others; thirdly, means of darting the sheaf of rays in any desired direction, whether by lenses or reflectors, by the help of which the sensitiveness of the receiver (apparently the most difficult of the problems to be solved) would not need to be so delicate as when the rays to be picked up are simply radiating into space in all directions, and fading away according to the law of inverse squares.

"I assume here that the progress of discovery would give instruments capable of adjustment by turning a screw or altering the length of a wire, so as to become receptive of wave-lengths of any preconcerted length. Thus, when adjusted to 50 yards, the transmitter might emit, and the receiver respond to, rays varying between 45 to 55 yards, and be silent to all others. Considering that there would be the whole range of waves to choose from, varying from a few feet to several thousand miles, there would be sufficient secrecy, for curiosity the most inveterate would surely recoil from the task of passing in review all the millions of possible wave-lengths on the remote chance of ultimately hitting on the particular wave-length employed by his friends whose correspondence he wished to tap. By 'coding' the message even this remote chance of surreptitious straying could be obviated.

"This is no mere dream of a visionary philosopher. All the requisites needed to bring it within the grasp of daily life are well within the possibilities of discovery, and are so reasonable and so clearly in the path of researches which are now being actively prosecuted in every capital of Europe that we may any day expect to hear that they have emerged from the realms of speculation into those of sober fact. Even now, indeed, telegraphing without wires is possible within a restricted radius of a few hundred yards, and some years ago I assisted at experiments where messages were transmitted from one part of a house to another without an intervening wire by almost the identical means here described."

The above vague reference to experiments on telegraphy without wires over a short distance was at a later date illuminated by the account given by Professor D. E. Hughes himself, of the precise nature of these hitherto undescribed experiments.[3] In the course of his work on the microphone, Professor D. E. Hughes had occasion to notice the wonderful sensitiveness of a "microphonic" or loose joint between conductors, and its variation of resistance under impacts, such as those of sound waves. He included such an "imperfect contact" in series with a voltaic cell and a telephone, and found that the resistance of certain kinds of contact was effected by electric sparks at a distance. Using a contact between carbon and steel, he no doubt constructed some form of self-restoring coherer, and made the important discovery that the discharge of a Leyden jar at a distance caused a sudden variation in its electrical resistance, and hence a sound in the telephone included in its circuit.

Professor D. E. Hughes stated in a letter addressed to Mr. Fahie, on April 29, 1899 (*loc. cit.*), that he showed these experiments in December, 1879, to Sir W. H. Preece, Sir William Crookes, Sir W. Roberts-Austen, Professor W. G. Adams, and Mr. W. Grove; also in February, 1880, to Mr. Spottiswoode, then president of the Royal Society, and to Professor Huxley, and Sir George Gabriel Stokes, the secretaries. In addition, he exhibited them to Sir James Dewar and Mr. Lennox. He was apparently discouraged from publishing the results at the time by finding that Sir George Stokes considered they were due to ordinary electromagnetic induction. It is, however, clear from the statements of Professor Hughes himself in 1899 that he had

[3] See a letter by Prof. D. E. Hughes in *The Electrician*, May 5, 1899, vol. 43, p. 40.

discovered (but not announced) in 1879 a number of facts afterwards rediscovered by Professor E. Branly in Paris in 1891, and he had, in fact, been using a self-restoring carbon-iron coherer in series with a telephone which was affected up to a distance of a few hundred yards by the electromagnetic waves created by an electric spark. If at the time he had publicly placed these observations on record, he would undoubtedly have anticipated some at least of Branly's work, but much remained to be done, which was subsequently done by Hertz and by Marconi, before electric wave wireless telegraphy, in any true sense of the word, could be translated from dream to fact.

Four years passed by, however, without any fulfilment of Crookes's scientific prophecy, although the most eminent physicists continued to work at the subject.

On January 1, 1894, the scientific world heard with profound regret of the death of Hertz.

On Friday, June 1, 1894, Sir Oliver Lodge delivered a memorial lecture on "The Work by Hertz," in the Royal Institution, London.

This lecture was remarkable in many ways. It gave many persons the opportunity of seeing, for the first time, striking experiments performed with Hertzian waves. The lecturer made use of a modified Branly's metallic filings tube, and also of a loose or imperfect metallic contact of his own invention, as a means of detecting the electric waves, and he gave to these devices the name *coherer*, by which they have since been known.

The tube was a glass tube loosely filled with iron borings and closed at the ends with metal plugs or caps. It is represented about one-third of full size in Fig. 3 of Chapter VI. The other form of coherer was a loose or microphonic contact between two pieces of metal, the pressure of which could be adjusted so that the junction offered too great a resistance to pass the current from a single cell, but *cohered* when electric waves fell upon it. In both cases the tapping back or decoherence was effected by hand after each experiment.

Experiments on the reflection, refraction, and polarization of these electric waves were shown, and their passage through stone walls from room to room. Yet, although replete with interest, the lecture, as originally delivered, contained not even a hint of a possible applications of these electromagnetic waves to telegraphy. The lecturer throughout fixed the attention of the audience on the similarity between the effects obtainable with these waves and those better known effects produced by rays of light.

It was, in fact, an experimental demonstration of the undulatory character of the electromagnetic radiation from an oscillator, and of the electromagnetic nature of ordinary light.

Subsequently the lecture was published as a book, the first edition of which bore the title, "The Work of Hertz and some of his Successors."[4]

These experiments and some variations of them were repeated at the meeting of the British Association at Oxford in the following autumn, but here again no mention of the application of these waves to telegraphy was made, the object of the experiments being to

[4] In later editions issued after 1896 the title was changed to "Signalling across Space without Wires."

illustrate an electrical theory of vision, and to expound the properties of the electric waves.[5]

It is highly probable that these articles and lectures, bringing home so forcibly the power of an electric spark to affect or make a deflection of a galvanometer at a distant place, must have turned the thoughts of many ingenious persons to its utilization as a means of sending telegraphic signals. Subsequently we were informed that the matter had begun to occupy the minds of Dr. A. Muirhead, Admiral Sir H. B. Jackson (then Captain in the Royal Navy), and Professor R. Threlfall, and perhaps many more.

Amongst others, Professor A. S. Popoff, Professor in the Imperial Torpedo School in Cronstadt, Russia, directed his attention to the subject, attracted to it by Lodge's lecture, and desirous, as he says, of repeating the experiments both for lecture purposes, and for registering electrical perturbations taking place in the atmosphere. His apparatus and wave detector have already been described (see Chap. VI. § 3), as well as the publication of his description of them, and experiments conducted with them in January, 1896, in the *Journal of the Physico-Chemical Society of St. Petersburg*.

It is beyond question, however, that the use he made of his apparatus was not the communication of intelligence to a distance, but for studying atmospheric electricity. The observations were made at the Institute of Forestry, St. Petersburg. Popoff says—

"Upon the building of the Institute, amongst other arrangements made for observing the direction and force of the wind, there was a small wooden mast about 4 sajen (28 feet) higher than the rods carrying the anemometers and weathercocks, and which was furnished at the top with an ordinary lightning point and rod. This lightning rod, by means of a wire carried first on the wood of the mast, and further stretched across the yard on insulators into the meteorological observatory, was connected with the apparatus at the point A (Fig. 2), whilst the point B was connected to a wire which served as an earth conductor or connection for the other meteorological apparatus, and was connected to the water-supply pipes. The registering arrangements consisted of an electromagnet, to the armature of which there was attached a Richard pen writing on a Richard recording cylinder, making one revolution per week. It was found that the apparatus responded by a ring of the bell to every closing of an electric circuit which was recording observations of the direction and force of the wind, since electric oscillations were then set up in the conductors connected with the apparatus by the common conductor leading to the earth plate. In order to distinguish these marks from the others made by atmospheric electricity, the observers, who produced the ringing, made a note each time on the cylinder. This action upon the apparatus was, however, useful for the purpose of being sure that it continued in good order."

That this primary object was not telegraphy is shown by the paragraph with which he concludes his paper (*loc. cit.*). He says—

"In conclusion, I may express the hope that my apparatus, with further improvements, may be adapted to the transmission of signals to a distance by the aid of quick electric vibrations as soon as a means for producing such vibrations possessing sufficient energy is found."

We are left, then, with this unquestionable fact that at the beginning of 1896, although the most eminent physicists had been occupied for nine years in labouring in the field of discovery laid open by

[5] See *The Electrician*, August 17, 1894, vol. 33, p. 458. For pictures of the Lodge apparatus exhibited at Oxford, see *The Electrician*, vol. 39, p. 687.

Hertz, and although the notion of using these Hertzian waves for telegraphy had been clearly suggested, no one had overcome the practical difficulties, or actually given any exhibition in public of the transmission of intelligence by alphabetic or telegraphic signals by this means. The appliances in a certain elementary form existed, the advantages and possibilities of electric wave telegraphy had been pointed out, but no one had yet conquered the real practical difficulties, and exhibited the process in actual operation.

2. Marconi's Work, 1895-1898.—Meanwhile, a young investigator had been busy in Italy. Guglielmo Marconi was born at Bologna on April 25, 1874, and very early displayed an original and inventive mind. He studied physics under Professor Rosa of the Leghorn Technical School, and made himself acquainted with the published writings of Professor Righi of the University of Bologna, whose valuable work on electromagnetic radiation was well known.

When little more than twenty years of age, Marconi had not only acquired much knowledge of Hertzian wave research, but he had clearly formed the intention of devoting himself to its utilization for effecting wireless telegraphy.

On his father's estate at the Villa Griffone, near Bologna, he began experimenting in June, 1895, with Hertzian waves, using an ordinary spark induction coil, and making for himself experimental coherers or various forms of the Branly tube. Before long he originated an important improvement. Instead of employing the Hertzian form of radiator, he connected one terminal of the secondary circuit of his induction coil to a metal plate or net laid on the ground, and the other by a wire to a metal can or cylinder, placed on the summit of a pole. The spark balls were kept at such a distance than on closing the primary circuit of the coil an oscillatory spark passed between them. At the receiving end he similarly connected a metallic filings sensitive tube between an earth plate and an insulated conductor or capacity. He then began systematically to examine the relation between the distance at which the spark could affect his coherer and the elevation of his cans or cylinders above the ground. This brought him speedily to the discovery that the higher the cans the greater the distance over which he could work.

Thus in 1895 he was using cubes of tin about 1 foot in the side as elevated conductors or capacities, and found that when placed on the tops of poles 2 ms. high he could receive signals at 30 ms. distance, and when placed on poles 4 ms. high at 100 ms., and at 8 ms. high at 400 ms. With larger cubes of 100 cms. side fixed at a height of 8 ms. Morse signals could be transmitted 2400 metres, or $1\frac{1}{2}$ miles all round.

Before this time, however, he had improved the Branly metallic filings tube, and produced his own nickel-silver filings sensitive tube already described (see Chap. VI. Fig. 4). He had combined this sensitive and regularly acting improved coherer with an electric-tapping arrangement, but with more careful insight into the conditions to be fulfilled and a greater range of adjustment than previous workers.

He added also to the filings tube a pair of inductances or choking coils, intended to prevent the electric oscillations passing through the

circuit in parallel with the tube, and compel them to expend their energy on the tube itself. He placed in series with the tube a single voltaic cell and a sensitive relay, and employed the relay to actuate a Morse printing instrument worked by a separate set of cells. In addition, he placed shunt circuits across the tapper break contacts and relay contacts to prevent sparking, and therefore disturbances of the sensitive tube by local effects.

Finally, he mounted the whole receiving arrangement on a board and enclosed the tube, tapper, and relay in a metallic box to shield them from the direct action of electric sparks made in their vicinity.

In the primary circuit of the induction coil at the transmitting end he placed a Morse sending key, and he connected the secondary terminals to the earth and to an elevated conductor as described. At the receiving end he connected, in the early experiments, one end of the coherer tube to an earth plate, and the opposite terminal to an elevated capacity. Lastly, he made such adjustments of the tapping arrangements that when a short series of oscillatory sparks were made at the induction coil by just depressing the Morse key in its primary circuit for one moment, the combination at the receiving end printed a *dot* on the Morse tap, and when the key was depressed for a longer time it printed a *dash*. In this manner the two signals required for forming an alphabet on the Morse code were obtained, and letters and words could be printed on the tape at the receiving end by properly handling the key at the transmitting end.

He employed at first the ball discharger of Professor Righi, which consisted of four solid brass balls, the two larger central ones being separated by a certain small interval, and the space between filled with vaseline oil kept in position by a non-conducting jacket or membrane.

In some experiments Marconi placed the discharge balls in the focal line of a cylindrical parabolic mirror, and the receiver in the focus of another similar mirror, using, for the purpose of collecting the wave energy, two metal strips or rods, attached to the extremities of the coherer tube.

In 1896 he came to England with this apparatus, and on June 2, 1896, he applied for a British patent, No. 12,039, for the invention, which was duly granted. The complete specification was filed March 2, 1897.[6]

In July, 1896, he introduced his invention and new method of telegraphy to the notice of Sir William Preece, then engineer-in-chief to the British Government Telegraph Service, who had for the previous twelve years interested himself in the development of wireless telegraphy by the inductive-conductive method.

On June 4, 1897, Sir W. H. Preece gave a lecture to a large audience at the Royal Institution in London on "Signalling through Space without Wires."[7] In this lecture, after expounding older and other methods, he devoted considerable time to exhibiting and

[6] The United States of America equivalent patent was numbered originally No. 586,193, applied for December 7, 1896, and issued July 13, 1897. After amendment it was reissued as No. 11,913, granted June 4, 1901.

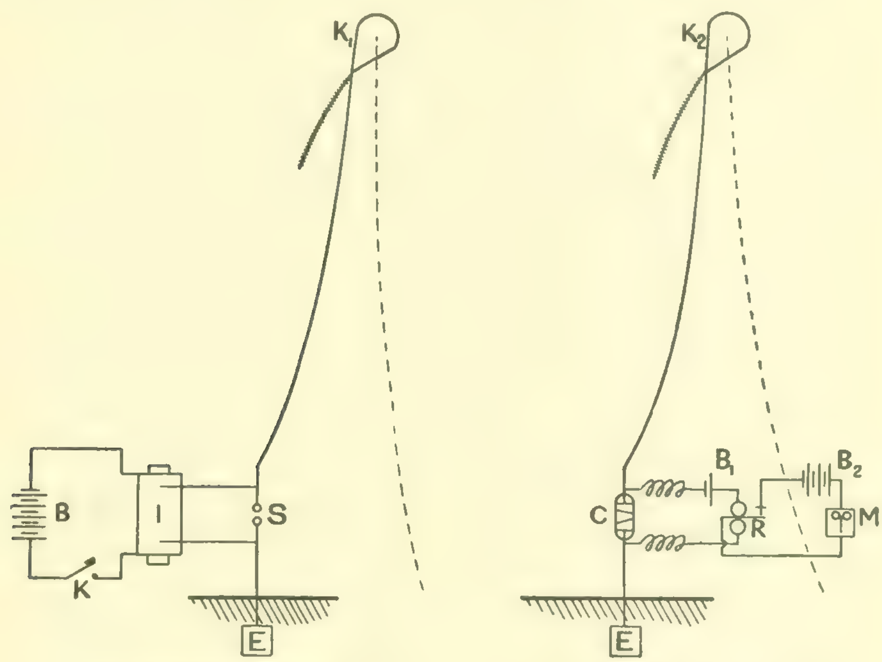
[7] See *The Electrician*, June 11, 1897, vol. 39, p. 216; also *Proc. Roy. Inst. Lond.*, 1897, vol. xv. p. 467.

explaining the Marconi apparatus, and spoke of it in the following terms :—

"In July last Mr. Marconi brought to England a new plan. Mr. Marconi utilizes electric or Hertzian waves of very high frequency. He has invented a new relay which for sensitiveness and delicacy exceeds all known electrical apparatus. The peculiarity of Mr. Marconi's system is that, apart from the ordinary connecting wire of the apparatus, conductors of very moderate length only are needed, and even these can be dispensed with if reflectors are used."

Testifying to its practicability as a telegraphic method, Sir William Preece said—

"Excellent signals have been transmitted between Penarth and Brean Down, near Weston-super-Mare, across the Bristol Channel, a distance of nearly nine miles. On Salisbury Plain Mr. Marconi covered a distance of four miles."



Transmitting station. *Receiving station.*

Fig. 1.—Marconi's Apparatus for Wireless Telegraphy in 1896. B, battery; I, induction coil; S, spark balls; K, sending key; E, earth plate; K_1, K_2, kites upholding aerial wires; C, coherer; R, relay; M, Morse printing instrument; B_1, B_2, batteries.

As regards the means used, it was stated that up to a distance of four miles a 6-inch spark coil sufficed, but for greater distances a 20-inch spark coil had been employed. In these experiments the method with reflecting mirrors was tried, but the chief part was carried out by connecting one terminal of the coherer and the spark coil secondary circuit respectively to earth, and each of the other terminals to nearly vertical wires upheld by masts, these wires terminating sometimes in metal plates or cylinders, or else the wires were upheld by balloons or kites covered with tinfoil in the manner shown in diagram in Fig. 1.

The evidence at this date all goes to show that the highest authorities on the subject admitted the novelty of Marconi's telegraphic method and appliances.

One technical paper (the London *Electrician*), after a column and a half of editorial comment on the Preece lecture, ended by saying—

"Meanwhile we wish Mr. Marconi, his apparatus and experiments, all possible success, if only because the evolution from Maxwellian equations and Hertzian vibrations of a thoroughly practical system of telegraphy will prove an excellent object lesson on the value of pure research."[8]

Sir William Preece, at the conclusion of his lecture, combated the contention, which appears to have been raised, that Mr. Marconi had done nothing new, and said (*loc. cit.*)—

"He has not discovered any new rays; his receiver is based on Branly's coherer. Columbus did not invent the egg, but he showed how to make it stand on its end, and Marconi has produced from known means a new electric eye more delicate than any known electrical instrument, and a new system of telegraphy that will reach places hitherto inaccessible. . . . Enough has been done to prove and show that for shipping and lighthouse purposes it will be a great and valuable acquisition."

The news of these successful demonstrations spread abroad and excited great interest. Amongst those who had been giving attention to the utilization of Hertzian waves was Professor A. Slaby, one of the Engineering Professors in the Technical High School at Charlottenburg, Berlin, and he at once hurried to England to discover how Marconi had solved a problem that had hitherto baffled him (Professor Slaby).

After seeing and assisting in the experiments across the Bristol Channel, Professor Slaby wrote a magazine article on "The New Telegraphy,"[9] and made the following remarks:—

"In January, 1897, when the news of Marconi's first successes ran through the newspapers, I myself was earnestly occupied with similar problems. I had not been able to telegraph more than one hundred metres through the air. It was at once clear to me that Marconi must have added something else—something new—to what was already known, whereby he had been able to attain to lengths measured by kilometres. Quickly making up my mind, I travelled to England, where the Bureau of Telegraphs was undertaking experiments on a large scale. Mr. Preece, the celebrated engineer-in-chief of the General Post Office, in the most courteous and hospitable way, permitted me to take part in these; and in truth what I there saw was something quite new. Marconi had made a discovery. He was working with means the entire meaning of which no one before him had recognized. Only in that way can we explain the secret of his success. In the English professional journals an attempt has been made to deny novelty to the method of Marconi. It was urged that the production of Hertz rays, their radiation through space, the construction of his electrical eye—all this was known before. True; all this had been known to me also, and yet I was never able to exceed one hundred metres.

"In the first place, Marconi has worked out a clever arrangement for the apparatus which by the use of the simplest means produces a sure technical result. Then he has shown that such telegraphy (writing from afar) was to be made possible only through, on the one hand, earth connection between the apparatus and, on the other, the use of long extended upright wires. By this simple but extraordinarily effective method he raised the power of radiation in the electric forces a hundredfold."

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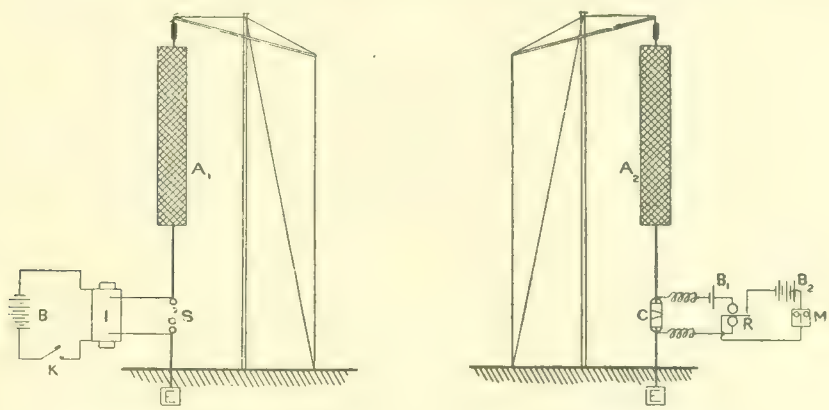
[8] See Editorial Notes, *The Electrician*, vol. 39, p. 208.

[9] See Dr. A. Slaby on "The New Telegraphy," *The Century Magazine*, April, 1898, vol. 55, p. 867.

The two and a half years between June, 1896, and December, 1898, were occupied by Marconi with numerous public demonstrations of the utility of his system of wireless telegraphy. Space cannot be afforded for a detailed history, but the general facts are as follows :—

The autumn of 1896 was occupied with experiments carried out before representatives of the British Government Postal Telegraph Department, and communication was established over a distance of 2 miles. Tests were also carried out in the presence of the Navy and Army representatives (Captain Jackson, R.N., and Major Carr, R.E.), on Salisbury Plain, during the month of March, 1897, when transmission over a distance of eight miles was demonstrated. In May, 1897, the experiments already described, between Penarth and Weston-super-Mare, were made across the Bristol Channel, a distance of nine miles. In July, 1897, Marconi undertook demonstrations for the Italian Government at Spezzia, in Italy, and covered a distance of 12 miles between warships. Communication was then set up by



Transmitting station. *Receiving station.*

FIG. 2.—Marconi's Apparatus for Wireless Telegraphy as used in 1896–98. A_1, A_2, strips of wire netting constituting the antennæ, upheld by insulators at the top of masts. The remaining letters refer to apparatus as mentioned under Fig. 1.

him between Alum Bay, in the Isle of Wight, and Bournemouth, England, a distance of about 14 miles over sea, and the working of the system was inspected by the author, in April, 1898. Marconi was at that time using as the transmitter a 10-inch spark induction coil, and a discharger consisting of four balls of brass, each about 2 inches in diameter, spaced slightly apart in an ebonite frame.

One of the outer balls was connected by a thick wire to an earth plate, and the other outer ball by a wire to an insulated strip of wire netting about 120 feet in length, which was upheld by an ebonite insulator attached to a sprit hauled up to the top of a 120-foot mast (see Fig. 2). These balls were also in connection with the secondary terminals of the induction coil, and the four brass discharge balls were set with air gaps about $\frac{1}{4}$ inch, or 5 to 6 mm., long between the balls. In the primary circuit of the induction coil was placed a massive Morse key with heavy platinum contacts. Marconi had at that time abandoned the use of the Righi discharger with balls

in oil. The receiver used was exactly as already described. With this apparatus telegraphic messages were sent in Morse code at about a rate of 12 to 15 five-letter words per minute. The working of this Isle of Wight to Bournemouth plant was inspected by many notable men, *e.g.* Lord Tennyson, Lord Kelvin, and others; and Lord Kelvin gave practical expression to his opinion that it was already in a commercial condition by paying for a message sent by him to Sir William Preece at the General Post Office, London, on June 3, 1898.

In May, 1898, communication was established for the Corporation of Lloyds between Ballycastle and the Lighthouse on Rathlin Island in the North of Ireland, the distance being 7·5 miles.

In July, 1898, the Marconi telegraphy was employed to report the results of yacht races at the Kingstown Regatta for the *Dublin Express* newspaper. A set of instruments were fitted up in a room at Kingstown, and another on board a steamer, the *Flying Huntress*. The aerial conductor on shore was a strip of wire netting attached to a mast 40 feet high, and several hundred messages were sent and correctly received during the progress of the races. The distances were from 5 to 20 miles.

At this time His Majesty King Edward VII., then Prince of Wales, had the misfortune to injure his knee, and was confined on board the royal yacht *Osborne* in Cowes Bay Mr. Marconi fitted up his apparatus on board the royal yacht by request, and also at Osborne House, Isle of Wight, and kept up wireless communication for three weeks between these stations. The shore mast was 105 feet high, and the wire on board the yacht 83 feet high. The distances covered were small; but as the yacht moved about, on some occasions high hills were interposed, so that the aerial wires were overtopped by hundreds of feet, yet this was found to be no obstacle to communication.

The success of these demonstrations led the Corporation of Trinity House to afford an opportunity for testing the system in actual practice between the South Foreland Lighthouse, near Dover, and the East Goodwin Lightship, on the Goodwin Sands. This installation was set in operation on December 24, 1898, and proved to be not only most successful, but of the greatest practical value. It was shown that when once the apparatus was set up it could be worked by ordinary seamen with very little training.

At the end of 1898 electric wave telegraphy had thus been established by Marconi on a practical basis. He had demonstrated its utility, especially for communication between ship and ship and ship and shore, a work which could not be accomplished by any other system.[10]

It had been shown that the advantages were as follows:—

(i.) It worked as well by night as by day, and in bad weather, fogs, or storms, as well as in fair weather; provided that the proper insulation of the aerial wire or elevated conductor was maintained.

(ii.) In certain electrical conditions of the atmosphere, and during thunderstorms, some difficulty was usually found in working, owing

[10] A summary of his work on wireless telegraphy up to the beginning of 1899 is given in a paper read by Mr. Marconi to the Institution of Electrical Engineers on March 2, 1899. See *Journal of the Inst. Elec. Eng.*, 1899, vol. 28, p. 273.

to the atmospheric discharges affecting the sensitive tube, and therefore making stray marks on the Morse tape of the printer, but seldom sufficient to interrupt communication altogether.

(iii.) The interposition of high hills, trees, or the curvature of the earth did not prevent communication, though slightly affecting the power required. It worked particularly well over sea surface, and between ships and shore stations.

(iv.) The apparatus could be set up and handled by any ordinary telegraphist, and the record was made on paper strip in the usual Morse code.

(v.) It easily covered distances far beyond those feasible or attained by other systems of wireless telegraphy.

By kind permission of the Marconi Wireless Telegraph Company.

Fig. 3.—The Haven Hotel, Sandbanks, Poole, and Wireless Telegraph Mast. At this station much of Mr. Marconi's research work on wireless telegraphy has been carried out since 1898.

(vi.) Lastly, the apparatus required was by no means costly, and, with the exception of the mast required for upholding the aerial wire, it occupied but little space, and was particularly adapted for use on board ship.

The general appearance of the collected sending and receiving apparatus required inside the station or cabin is shown in Fig. 10.

3. Marconi's Improvements in 1898 and 1899.—Marconi was desirous of working over still greater distances than those already covered, but the difficulties of erecting masts for elevating the aerial conductor beyond a certain height were considerable. A mast 100

or 120 feet high is a comparatively simple thing to set up. It can be erected in three sections, and the aerial wire can be supported by insulators from a cross sprit at the top (see Fig. 3).

At the beginning of 1899, masts 120 to 140 feet high were employed, and an aerial wire consisting of a stranded copper wire 7/20 or 7/22 (generally an indiarubber insulated wire) was used. Very often a cylinder of wire netting was attached at the top or insulated end, and sometimes two or more aerial wires in parallel were used. The insulators were round rods of ebonite, about 24 inches long and 1 inch in diameter. When using simple wires and the receiving and transmitting apparatus of the 1896–1898 type, Marconi had found that the maximum distance which could be covered seemed to increase

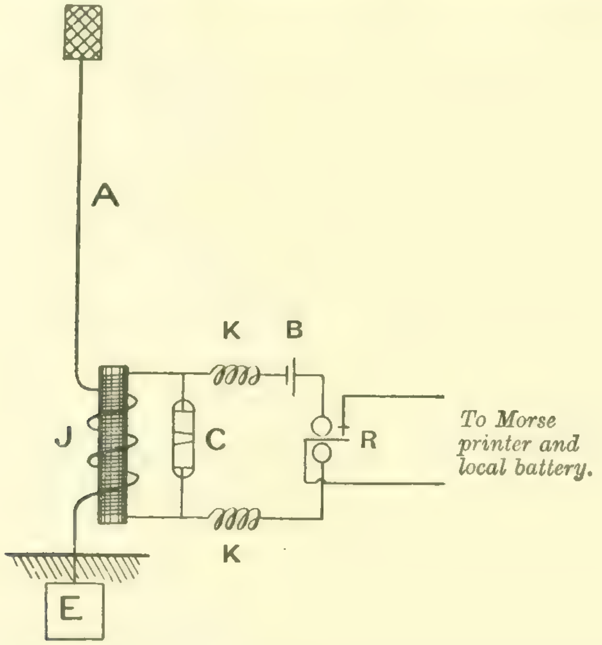


FIG. 4.—A, receiving antenna, or aerial wire, with capacity plate at summit; J, jigger, or oscillation transformer; C, coherer, or sensitive tube; E, earth plate; R, relay; B, relay cell; K, K, choking coils.

in proportion to the square of the height of the aerial wire, so that with aerials 100 feet high at each end the maximum working distance was four times that obtained with aerials 50 feet high.

He introduced, however, at this date an improvement into his receiving arrangements which had the result of increasing its sensitiveness. Instead of inserting the sensitive metallic filings tube or cymoscope directly between the earth plate and the bottom of the receiving aerial wire, an oscillation transformer of a particular form was interposed (see Fig. 4).

In considering the production of stationary electric oscillations in wires in Chap. IV., it has been explained that if a vertical wire is set up with its lower end in connection with an earth plate, then when the fundamental oscillation is set up in the wire we have a node of

potential and an antinode or maximum of current at the lower or earthed end of the aerial.

If, then, we cut this aerial wire near the earth and insert a coherer between the earth plate and the aerial wire, the production of oscillations in the wire only results in establishing a relatively small difference of potential between the terminals of the coherer. This instrument is, in fact, being employed in a very inefficient manner, and inserted in the wrong place. We shall see later on that Professor Slaby found another ingenious solution of this problem. Marconi, however, adopted the plan of inserting in the base of the aerial wire near the earth the primary coil of a small air core transformer, J, of a peculiar kind, the secondary terminals of which were connected to the sensitive tube, C (see Fig. 4). In this manner the large current existing near the base of the aerial was, so to speak, transformed into high voltage for use at the terminals of the coherer. To do this effectively, however, requires a special form of transformer. Lodge had previously suggested in a British patent specification the employment of a transformed oscillation for affecting the coherer so that it was operated by secondary oscillations, and not directly by those in the receiving rods.[11] Lodge, however, gave no details of construction, and from the diagram in his specification it is impossible to determine the dimensions and the nature of the circuits suitable for making a transformer which will be operative in any given case. Marconi discovered, after innumerable experiments, the proper form to give to such an oscillation transformer, and particularly described it in patent specifications and lectures.

Marconi's oscillation transformer, or "jigger," in one form consists of a glass tube about 1 cm. in diameter and 4 to 8 cms. in length. On this is wound a primary circuit consisting of a length of silk-covered copper wire, which may vary in diameter, according to circumstances, from No. 26 to No. 40 S.W.G. This coil is put on in one layer, or in two or more layers, which may be joined in parallel or in series.

The total length of primary wire may be from 3 to 20 feet or more, but is determined by the aerial used. The secondary circuit is wound over the primary, and is generally a silk-covered copper wire of size No. 36 or No. 40 S.W.G. It may have a length of 100, 150, or even 1000 feet or more, according to the wave length used. It was asserted to be an advantage to wind this secondary circuit in a peculiar manner, not putting it on in level layers, but bunching it in sections, each layer in each section consisting of a smaller number of turns than the preceding and inner layer. This mode of winding is indicated in the diagrams in Fig. 5, which are half-sections of various oscillation transformers, the thick black lines standing for layers of primary wire and the thinner lines for layers of secondary wire. The annexed tables give the numbers of the primary turns and the secondary turns in the various tapering bunches for two particular oscillation transformers described by Marconi in his first British Patent Specification on the subject.[12]

[11] See Lodge's British Patent, No. 11,575, of 1897.

[12] See British Patent Specifications, No. 12,326, of June 1, 1898; also No. 6982, of April 1, 1899, granted to G. Marconi and others.

Jigger No. 1. Primary.	Jigger No. 1. Secondary.	Jigger No. 2. Primary.	Jigger No. 2. Secondary.
2 layers of 160 turns each, in parallel	3 sections of 9, 11, 9 layers, with 150 45 40 45 40 39 40 35 37 35 30 35 30 25 33 25 20 29 20 15 25 15 12 21 17 5 15 14 10 5 turns respectively	2 layers of 160 turns each, in parallel	4 sections of 9 layers, with 40 | 80 | 40 35 | 35 | 35 | 35 30 | 30 | 30 | 30 27 | 27 | 27 | 27 23 | 23 | 23 | 23 20 | 20 | 20 | 20 15 | 15 | 15 | 15 10 | 10 | 10 | 10 5 | 5 | 5 | 5 turns respectively

This mode of winding the jigger in layers of gradually decreasing number of turns was later on found not to be of any marked utility and was abandoned in favour of a more simple form of cylindrical winding. The matter of practical importance is the ability to alter at pleasure the *coupling* of the two circuits, viz. the quantity $\frac{M}{\sqrt{LN}}$, where M is the coefficient of mutual inductance of the two circuits

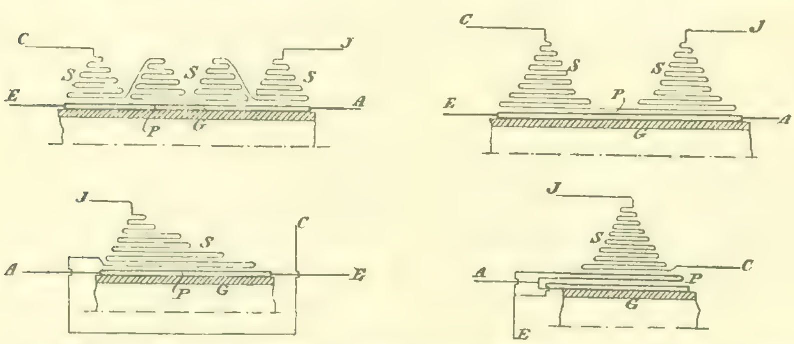


FIG. 5.—Half-sectional Diagrams illustrating Various Early Forms of Jigger, or Receiving Oscillation Transformer, used by Marconi. The fine zigzag lines denote layers of silk-covered wire, and the crossed line is the section of one side of a glass tube on which the wire is wound.

and L and N their self inductances. Hence in more modern types of jigger or oscillation transformer the coils are so arranged that their distances or *coupling* can be altered. If both coils are wound on cylindrical formers or tubes, one can be slid into or out of the other. If they are wound as flat spirals they can be fixed to two hinged boards or otherwise arranged so as to vary their distance.

In a third British Patent Specification (No. 25,186, of December 19, 1898) Marconi described an additional improvement. He divided the secondary circuit into two parts, and separated their inner ends by a small condenser j^3 made of paraffined paper and tinfoil sheets. The outer ends of the secondary circuit were connected to the sensitive

tube or coherer, T, and the inner ends of its two sections were connected through two choking coils to the relay or local telegraphic instrument (see Fig. 6). The reason for this construction is that the outer ends of the secondary circuit are potential antinodes or loops, and by joining in the local or relay circuit in the centre of the secondary circuit, as shown, less interference is produced in the amplitude of the potential variation at the tube terminals than if the relay circuit was connected to these terminals, as previously the case.

In this specification Marconi gave details of the windings of two "jiggers" suitable for working with sending and receiving aerials 140 feet high, the transmitting system being the simple aerial directly connected to one secondary spark ball of an induction coil as already described.

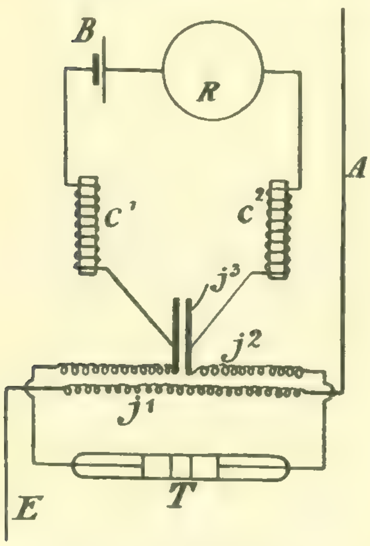


FIG. 6.—Arrangement of Apparatus in Marconi Receiver for Electric Wave Telegraphy. A, antenna; E, earth wire; T, sensitive tube, or cymoscope; j^1, j^2, circuits of jigger; j^3, condenser in centre of jigger secondary; c^1, c^2, choking coils; R, relay; B, relay battery.

"The specification for these transformers is as follows: The following are the details of the coil shown in Fig. 7. The primary is wound on a core 0·6 cm. in diameter, and consists of 100 turns of copper wire 0·037 cm. (No. 28 S.W.G.) in diameter, insulated with single silk covering and coated with paraffin wax. The secondary is of copper wire 0·019 cm. (No. 36 S.W.G.) in diameter, insulated with single silk covering, and is wound over the primary, commencing in the middle and in the same sense as the primary. Each half of the secondary is in layers of the following number of turns: first layer, 77; second, 49; third, 46; fourth, 43; fifth, 40; sixth, 37; seventh, 34; eighth, 31; ninth, 28; tenth, 25; eleventh, 22; twelfth, 19; thirteenth, 16; fourteenth, 13; fifteenth, 10; sixteenth, 7; seventeenth, 3; making 500 in all."

The following are the details of another coil described in the same patent specification:—

"The primary wound on a core 2·5 cms. in diameter consists of 50 turns of copper wire 0·07 cm. (No. 22 S.W.G.) in diameter, insulated with single silk covering. The secondary is of copper wire 0·005 cm. (No. 47 S.W.G.) in diameter, insulated by a single silk covering, and is wound over and in the same sense as the primary. Each half of the secondary consists of 160 turns in a single layer."

The inventor points out that the best results are obtained when the secondary circuit of the oscillation transformer has a total length equal to that of the transmitting aerial. This, however, must be understood to apply to the form of simple transmitting aerial up to that time used. We shall consider more particularly in another chapter the general physical theory of these oscillation transformers.

A large variety of forms of receiving oscillation transformer have at various times been employed by Marconi, and it forms a very important element in his system. In order to secure good results, or, in fact, any result at all, the length of the secondary circuit of this

receiving oscillation transformer must bear a certain relation to the length of the wave used.

The types of oscillation transformer the details of which are given above were found to be suitable for working with a wave length of about 600 or 700 feet, corresponding to an aerial 140 feet in height, when the transmitting arrangements were as already described. If the oscillation transformer, or *jigger*, is not wound to suit the wave length employed, so far from being a benefit, it prevents any signals being received at all.

The employment of a properly designed oscillation transformer in the receiving aerial was, however, found by Marconi to increase very considerably the range of working of the apparatus when using the receiving arrangement comprising the metallic filings tube as already described. Hence, towards the end of 1898 he was able to attempt wireless telegraphy over still greater distances than he had been able previously to accomplish.

4. Marconi's English Channel Experiments in 1899.—Just before Easter, 1899, Marconi obtained from the French Government permission to erect a mast for wireless telegraph experiments at

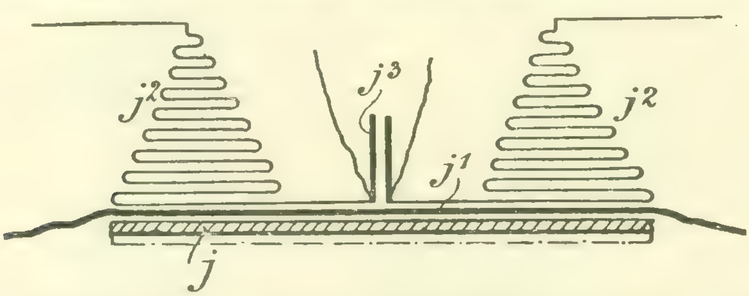


FIG. 7.—Half-section of Jigger, as used in Receiver shown in Fig. 6. j^1, jigger primary circuit; j^2, jigger secondary circuit; j^3, jigger condenser.

Wimereux, near Boulogne, in France, and a corresponding mast was erected at the South Foreland Lighthouse, near Dover, on the coast of England. The distance of these stations from one another was 32 miles (50 kilometres).

The apparatus for sending and receiving was erected in a small room in the South Foreland Lighthouse on the English side of the Channel, and on the French side in the Chalet d'Artois, at Wimereux (see Fig. 8).

The aerial wires were single-stranded copper wires 150 feet long, insulated with indiarubber, and upheld at the top by ebonite rods as insulators. As soon as the plant was complete Marconi transmitted messages, on March 27, 1899, across the English Channel, and sent communications in this manner from Wimereux to numerous scientific friends in England. The result was to create an immense public interest in the achievement all over the world. Up to that moment wireless telegraphy by electric waves had attracted only a very limited general attention; but the bridging of the English Channel by electric waves was one of those sensational feats which at once aroused the daily press to lively comment on the matter. The author, after spending some time in examining the appliances and working, wrote

a letter to the *Times*, published on April 3, 1899, part of which was as follows :—

"During the last few days I have been permitted to make a close examination of the apparatus and methods being employed by Signor Marconi in his remarkable telegraphic experiments between South Foreland and Boulogne, and at the South Foreland Lighthouse have been allowed by the inventor to make experiments

By kind permission of the Marconi Wireless Telegraph Company, Ltd.

FIG. 8.—**Mast and Antenna Wire at the Chalet d'Artois, Wimereux, Boulogne, whence the first wireless messages were sent across the English Channel in March, 1899, by Mr. Marconi.**

and transmit messages from the station there established both to France and to the lightship on the Goodwin Sands, which is equipped for sending and receiving ether wave signals. Throughout the period of my visit, messages, signals, congratulations, and jokes were freely exchanged between the operators sitting on either side of the Channel, and automatically printed down in telegraphic code signals on the ordinary paper slip at the rate of twelve to eighteen words a minute. Not once was there the slightest difficulty or delay in obtaining an instant reply to a signal sent. No familiarity with the subject removes the feeling of vague

wonder with which one sees a telegraphic instrument merely connected with a length of 150 feet of copper wire run up the side of a flagstaff begin to draw its message out of space and print down in dot and dash on the paper tape the intelligence ferried across 30 miles of water by the mysterious ether.

"The apparatus, moreover, is ridiculously simple and not costly. With the exception of the flagstaff and 150 feet of vertical wire at each end, he can place on a small kitchen table the appliances, costing not more than £100 in all, for communicating across 30 or even 100 miles of channel. With the same simple means he has placed a lightship on the Goodwins in instant communication, day and night, with the South Foreland Lighthouse. A touch on a key on board the lightship suffices to ring an electric bell in the room at South Foreland, 12 miles away, with the same ease and certainty with which one can summon the servant to one's bedroom at an hotel. An attendant now sleeps hard by the instruments at South Foreland. If at any moment he is awakened by the bell rung from the lightship, he is able to ring up in return the Ramsgate lifeboat, and, if need be, direct it to the spot where its services are required, within a few seconds of the arrival of the call for help. In the presence of the enormous practical importance of this feat alone, and of the certainty with which communication can now be established between ship and shore without costly cable or wire, the scientific criticisms which have been launched by other inventors against Signor Marconi's methods have failed altogether in their appreciation of the practical significance of the results he has brought about.

"Up to the present time none of the other systems of wireless telegraphy employing electric or magnetic agencies has been able to accomplish the same results over equal distances. Without denying that much remains yet to be attained, or that the same may not be effected in other ways, it is impossible for any one to witness the South Foreland and Boulogne experiments without coming to the conclusion that neither captious criticism nor official lethargy should stand in the way of additional opportunities being afforded for a further extension of practical experiments. Wireless telegraphy will not take the place of telegraphy with wires. Each has a special field of operations of its own, but the public have a right to ask that the fullest advantage shall be taken of that particular service which ether wave telegraphy can now render in promoting the greater safety of those at sea, and that, in view of our enormous maritime interests, this country shall not permit itself to be outraced by others in the peaceful contest to apply the outcome of scientific investigations and discoveries in every possible direction to the service of those who are obliged to face the perils of the sea. If scientific research has forged a fresh weapon with which in turn to fight nature, 'red in tooth and claw,' all other questions fade into insignificance in comparison with the inquiry how we can take the utmost advantage of this addition to our resources."

Although many scientific men at that time refused to admit that these cross-Channel experiments were indications of the utility of the Marconi telegraphy, some of the remarks in the author's letter to the *Times* just quoted received singular confirmation a few days later. During a dense fog on the Channel on April 28, 1899, a steamer, the *R. F. Matthews*, outward bound, ran into the East Goodwin Lightship and inflicted serious damage. The lightship, however, being provided with the Marconi apparatus, was able to communicate at once with the station at South Foreland Lighthouse, and tugs and a lifeboat were sent out immediately from Ramsgate to the assistance of the lightship. But for this timely aid the lightship would most probably have sunk. These demonstrations were continued uninterruptedly during the year 1899.

In the autumn of that year the British Association held its annual assembly at Dover. This meeting, taking place just a hundred years after the date of Volta's epoch-making invention of the Voltaic pile, was made the occasion of certain celebrations. The author, by request, delivered an evening discourse on "The Centenary of the

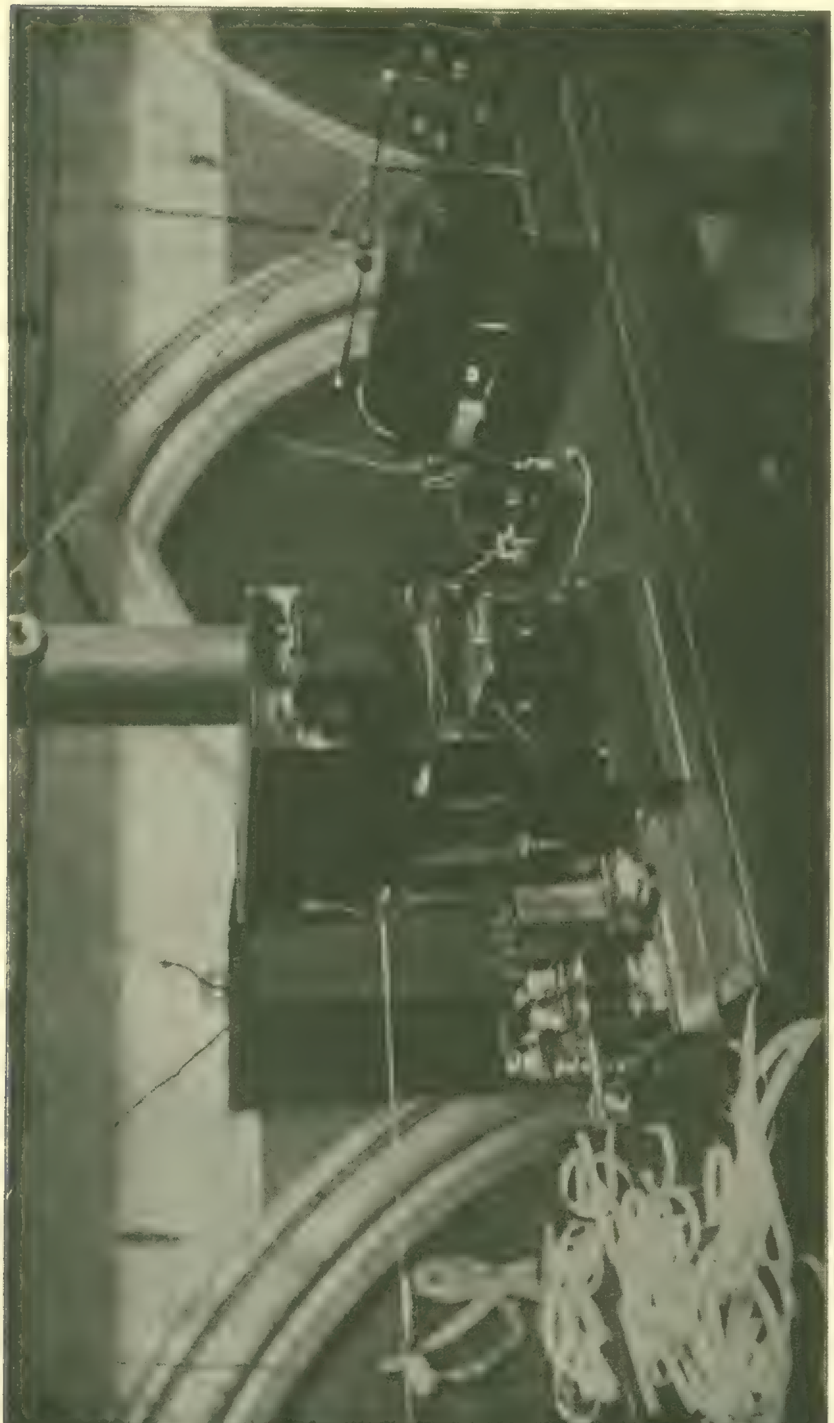
Electric Current" before the British Association in the Town Hall, Dover. At his suggestion a mast had been erected on the tower for the purposes of wireless telegraphy (see Fig. 9). The Marconi apparatus was set up on the lecture table and placed in direct

From "The Electrician."

FIG. 9.—Mast and Marconi Aerial Wire erected on the Tower of Town Hall, Dover, August, 1899, for Reception of Messages from France during the Meeting of the British Association in September.

communication with the South Foreland Lighthouse (4 miles), with Wimereux, in France (33 miles), and with the East Goodwin Lightship (12 miles) (see Fig. 10).

During the lecture messages were sent to the President of the



From "The Electrician."

FIG. 10.—Marconi Wireless Telegraph Apparatus arranged on the Lecture Table in the Town Hall, Dover, for a Lecture by Dr. J. A. Fleming, F.R.S., on "The Centenary of the Electric Current," before the British Association, September, 1899.

French Association for the Advancement of Science (M. Brouardel), then meeting at Boulogne, and numerous messages exchanged with the South Foreland station and the East Goodwin Lightship. Subsequently messages were sent from Wimereux, in France, and received directly at a Marconi station established at Chelmsford, in England, a distance of 85 miles, of which 30 miles were over sea and 55 miles over land. The height of aerials at both stations was 150 feet.

In the same year, the interest of the public being greatly aroused over the races for the International Cup between British and American yachts, Mr. Marconi went over to the United States and employed his apparatus and system of telegraphy between a ship and the shore, for reporting the results of the races during their progress, for the *New York Herald* newspaper. Over four thousand words were transmitted in less than a total of five hours' work done on different days.

A more important application was, however, made in July and August, 1899, during the naval manœuvres of the British Navy. Three vessels of the Reserve Squadron were fitted with the apparatus, and most important evolutions were carried out by orders given by Marconi wireless telegraphy. Two cruisers (*Juno* and *Europa*) were equipped, and in some cases important orders and information were transmitted instantly 85 miles. A full account of the result obtained was published by Commander S. Statham, R.N.[13] In this work the value of the oscillation transformer in the receiving aerial was fully demonstrated, and also the fact that the curvature of the earth seemed in no way to interfere with the transmission of the electromagnetic waves radiated from the aerials even over great distances. These demonstrations assisted to establish electric wave wireless telegraphy both for naval and mercantile marine purposes on a firm basis.

Contracts with large transatlantic shipping companies, and agreements with the Corporation of Lloyd's for establishing coast stations, and regular and permanent services of wireless communication between ship and ship and ship and shore, were soon after made by Marconi's Wireless Telegraph Company, Limited.[14]

By the end of 1900 the new supermarine wireless telegraphy had taken an unassailable position as an essential aid to navigation, commerce, and naval operations.

5. Marconi's Work on Syntonic Wireless Telegraphy, 1899–1901.—From the very commencement of practical electric wave telegraphy it was recognized that some means must be found for limiting the receptivity of wireless telegraph stations. The simple form of wave-detecting arrangement, first used by Marconi before he introduced the peculiar oscillation transformer just described, is sensitive to electric waves varying very considerably in wave length; in fact, a single electromagnetic impulse, or so-called solitary wave, if

[13] See article in the *Army and Navy Illustrated*, August, 1900; also a Friday Evening Discourse at the Royal Institution by G. Marconi, February 2, 1900, *Proc. Roy. Inst.*, vol. xvi. No. 94, p. 251.

[14] The Wireless Telegraph and Signal Company, Limited, was registered on July 20, 1897, with a capital of £100,000, to work the Marconi system of wireless telegraphy and manufacture the Marconi apparatus. In 1900 the name was changed to that of Marconi's Wireless Telegraph Company, Limited.

strong enough, will affect it. Hence atmospheric electrical discharges and stray or vagrant waves sent out by any source are picked up by it.

Several distinct problems here present themselves. In the first place, we may desire to make any given receiving station normally responsive only to electromagnetic waves of one particular wave length. In the next place, we may wish to render that station proof against deliberate attempts to hinder communication by throwing on to it violent vagrant or disturbing waves. Thirdly, we may want to prevent foreign stations from picking up messages not intended for them which are being sent out from some transmitter, and intended only for some particular receiving station.

The first problem is an easier one to solve than the second and third. We shall defer to a later section the consideration of the different practical solutions which have been offered of these problems, and confine ourselves here to a brief description of Marconi's work in 1900 on this subject. All the methods he has so far adopted are based upon the principle of resonance or syntony, and upon the fact that oscillations of different frequency can coexist in circuits which have a common part.

Early in 1900 Marconi applied for a British patent (No. 7777 of April 26, 1900), in which appliances were described for conducting syntonic telegraphy as well as simultaneous multiplex telegraphy with single aerials.

Some mention of these advances was made by the author in a letter published in the *Times* of October 4, 1900, in which the results of certain remarkable demonstrations given in the previous month were described. Reference was also made to them in Cantor lectures on "Electric Oscillations and Electric Waves," given by the author to the Society of Arts in November and December, 1900; and they were subsequently more fully discussed in a paper read to the Society of Arts by Mr. Marconi on May 15, 1901, entitled "Syntonic Wireless Telegraphy." [15]

The particulars of the apparatus described in the above-mentioned specification of Marconi are as follows:—

At the transmitting end the original arrangement of an aerial wire connected to one spark ball of the induction coil, the other being earthed (now called a plain aerial), was exchanged for an aerial consisting of a pair of inductively coupled circuits. A condenser, usually taking the form of a battery of Leyden jars, had one terminal connected to one spark ball of an induction coil, and the other to the primary circuit of an oscillation transformer. The opposite terminal of this transformer circuit was joined to the second spark ball. These spark balls were placed, as usual, in connection with the secondary terminals of an induction coil. The secondary circuit of this oscillation transformer was inserted between the aerial wire and the earth plate, and an adjustable inductance coil included in the circuit (see Fig. 11).

The oscillation transformer is constructed as follows: It consists of a square wooden frame, wound over with a number of lengths of highly insulated, thick-stranded copper cable joined in parallel, so as

[15] See *Journal of the Society of Arts*, issue for May 17, 1901, vol. 49, p. 505.

to make a primary circuit of one turn of extremely low resistance. In some cases two or more turns may be employed. Over this is wound a secondary circuit of 5 to 10 turns, and the oscillation transformer is usually immersed in a vessel of highly insulating oil. This secondary circuit is joined in between the aerial and the earth, a variable inductance being interposed. When in position the oscillation transformer forms an inductive coupling between two circuits – one a nearly closed oscillation circuit of large capacity and small inductance, and the other an open oscillation of much smaller capacity and greater inductance.

These circuits are more or less closely "coupled" by varying the distance between the primary and secondary. By the adjustment

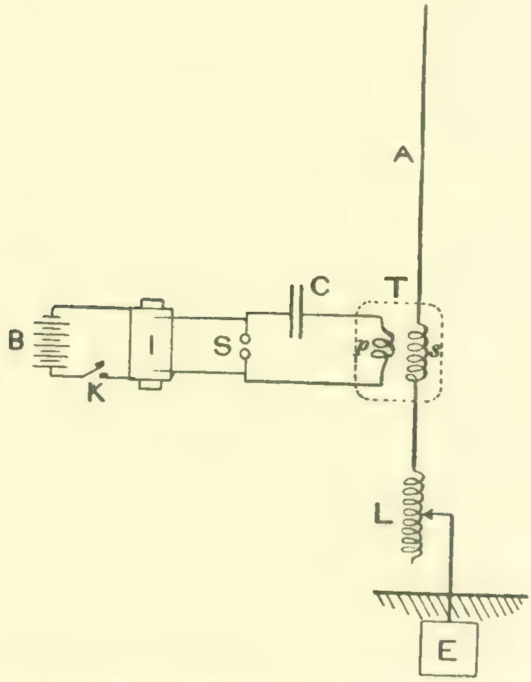


FIG. 11.—Arrangement of Transmitting Apparatus in Marconi System of Syntonic Wireless Telegraphy. A, antenna; L, tuning inductance; E, earth plate; *p*, *s*, oscillation transformer; C, condenser; S, spark balls; I, induction coil; B, battery; K, sending key.

of the variable inductance inserted between the earth plate and the secondary circuit of the oscillation transformer, and by variation of the capacity of the condenser in the primary circuit, the two circuits are brought into resonance with each other. When oscillations are set up in the closed circuit by the discharge of the condenser, the energy stored up in the Leyden jars is gradually drawn off and radiated by the open circuit. The closed circuit thus forms a reservoir of energy, and it is in itself a slightly damped circuit or persistent oscillator. The open circuit is a good radiator, and is kept supplied with energy by the reservoir. Hence we have a much more persistent train of oscillations set up in the aerial at each discharge than would be the case if the only storage of energy were that due to the

small capacity of the aerial. The important matter, however, is the proper "tuning" of the two coupled circuits. This can be effected in several ways:—

One plan is to employ a hot-wire voltmeter which is connected to two points on the circuit of the earth wire leading from the secondary circuit of the oscillation transformer to the earth plate. When oscillations are set up in the aerial, there is a difference of potential between these points, and the needle of the hot-wire voltmeter makes a more or less steady deflection. This reading depends not only upon the maximum value of the oscillatory current during each train of oscillations, but upon the logarithmic decrement, and upon the number of groups of oscillations which take place per second. If the spark gap remains the same length, and the number of spark discharges per second is kept constant, then any change in the capacity of the condenser in the primary circuit or in the inductance of the aerial circuit will make this voltmeter reading either greater or less. We then make some small change in one of these factors, say the condenser capacity, such that the voltmeter reading is slightly increased. We then continue in the same direction until the voltmeter reading begins to decrease again. In this manner we can tell approximately when we have given such value to the capacity that the current in the aerial is a maximum for a given spark length and spark frequency. This indicates that the two coupled oscillation circuits are approximately in syntony. Another method is to alter the inductance in series with the aerial and secondary circuit of the oscillation transformer until the maximum potential difference between terminals of this secondary circuit is reached, as evidenced by the spark discharge between them being of the greatest possible length.

For the purposes of this test, a sliding ball discharger, highly insulated, with means for easily altering the distance of the balls, is joined across the secondary terminals of the transformer.

A third method is to hold a rectangle of wire near the lower part of the aerial, the rectangle having inserted in it a vacuum tube, preferably one containing rarefied neon.[16] If the rectangle is placed with one side parallel to and near the aerial, the oscillatory currents induced in it will cause the vacuum tube to glow. We now alter either the inductance or capacity in either of the circuits, and notice whether the tube glows at a greater or less distance from the aerial, and so proceed to make small changes until we have succeeded in making the tube glow at the greatest possible distance from the aerial. This indicates that we have produced the maximum oscillation of current in the aerial. The spark length and spark frequency must, of course, remain unchanged during the test.[17]

Turning next to the receiver, the diagram of connections of Marconi's syntonic receiver is shown in Fig. 12.

A is the aerial wire, which may or may not be terminated in a plate

[16] The advantages of using rarefied neon in a vacuum tube as a means of detecting electrical oscillations were first pointed out by the author in a paper read to the British Association in 1904. See *Phil. Mag.*, October, 1904, p. 419.

[17] Another and more effective means is to employ the author's cymometer to make a measurement of the oscillation constant of the open and closed circuit respectively, and then to adjust the circuits so that they have the same oscillation constant. See Chap. VI. § 16.

or cylinder, *f*. At the foot of this aerial is an adjustable inductance, *g*, and this is connected to an earth plate, E, through the primary circuit, j^1, of an oscillation transformer. The terminals of this transformer are connected by a small sliding condenser, *h*. The secondary circuit, j^2, of this transformer is cut in the middle, and a condenser, j^3, inserted. The outer terminals of the secondary circuit are connected through two small variable inductances, g^1 and g^2, with the terminals of the sensitive tube, T, and are also connected by an adjustable condenser, h'. From the terminals of the middle condenser, j^3, proceed

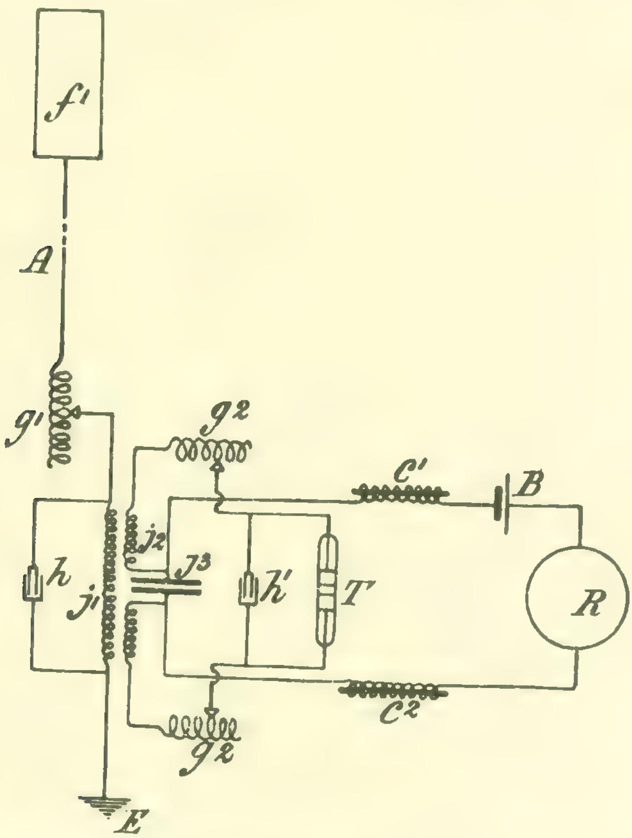


FIG. 12.—Arrangement of Receiving Apparatus in Marconi System of Syntonic Wireless Telegraphy. A, antenna; E, earth plate; g^1, g^2, tuning inductance; j^1, j^2, jigger; j^3, jigger condenser; c^1, c^2, choking coils; T, sensitive tube, or coherer; R, relay; B, battery.

two wires, which pass through choking coils, C^1 and C^2, and include the relay, R, and local cell, B, for working the relay. The Morse inker or other telegraphic instrument and associated battery connected to the relay are omitted from the diagram. The oscillation transformer, or jigger, placed in this receiving arrangement has its secondary circuit wound as already described in Marconi's three British Specifications, No. 12,326 of 1898, and Nos. 6982 and 25,186 of 1899 (see § 3 of this chapter).

To syntonize the receiver with itself and with the transmitter, the

two circuits, viz. the open circuit, comprising the receiving aerial, and the closed circuit, comprising the secondary circuit of the oscillation transformer, and the inductances g^1 and g^2, and the condensers j^3 and h' in series with it, must be adjusted so that this open and closed circuit are in resonance with each other, and have the same natural time period as the transmitter circuits intended to correspond with them. These different frequencies are technically termed the various *tunes*, and the operation of putting the circuits into syntony or resonance is called *tuning* the receiver and transmitter to themselves and to each other.

In his British Patent Specification, No. 7777 of 1900, Marconi gives the details for nine *tunes*. For example, one tune he calls No. 7, and he gives the particulars of the transmitter and receiver as follows:—

The transmitting aerial consists of four vertical stranded 7/22 copper wires, each 48·6 ms. long, connected together at the top or insulated end, but kept apart throughout their length by being suspended from the arms of a wooden cross, each arm of which is 4 ms. long.

The capacity in the primary of the oscillation circuit consists of a number of Leyden jars in parallel, having a total capacity of 0·016 mfd.

The oscillation transformer consists of a square wooden frame, the side of which is 30·48 cms., or 12 inches, in length, wound over with a primary circuit of one turn, the total length of the primary being 150 cms. The secondary circuit consists of six turns of insulated wire wound on the same frame, three turns on each side of the primary. These two circuits are made of highly insulated indiarubber-covered stranded copper cable, and the transformer, when made, is immersed in a vessel of highly insulating oil.

The oscillation transformer in the receiver has a secondary circuit consisting of 73·15 ms. of single silk-covered copper wire, No. 40 S.W.G., wound in one layer on a glass tube 5 cms. in diameter. The secondary is divided at its middle point. There are two primary circuits, each consisting of 2·75 ms. of copper wire 0·7 mm. in diameter, wound on tubes 6·5 cms. in diameter. The two primaries are placed over the two sections of the secondary circuit, and are joined in parallel. Another tune he calls No. 8, and gives particulars as follows:—

The transmitting aerial consists of a single stranded 7/22 copper wire 48 ms. long.

The condenser in the primary circuit of the transmitter consists of one or more Leyden jars having a total capacity of 0·007 mfd. The oscillation transformer in the transmitter has a primary circuit consisting of ten insulated wires, each 1·5 ms. in length, wound once round a square frame, the size of which is 30 cms., the ten wires being joined in parallel. The secondary circuit consists of 48·64 ms. of insulated wire, wound over the primary in 16 layers, the first or inner layer having nine turns, the second eight turns, the remainder seven, six, five, and two turns respectively.

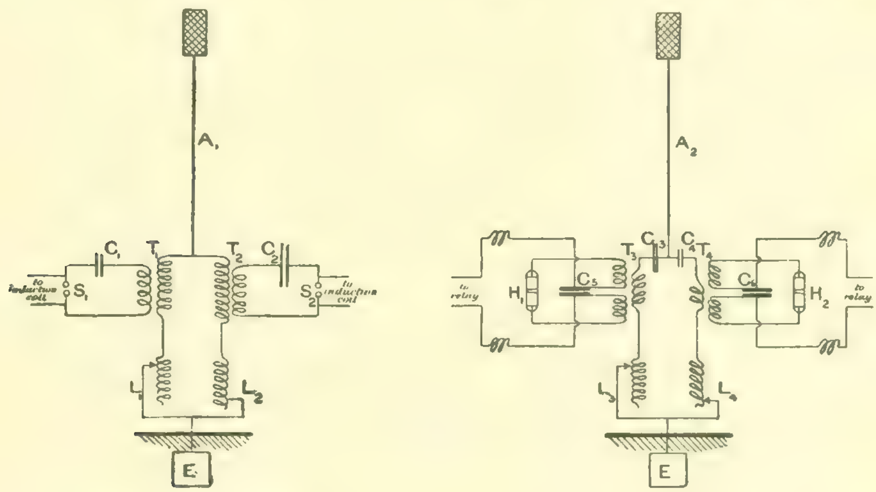
The oscillation transformer in the corresponding receiver has a secondary circuit consisting of 48·64 ms. of single silk-covered copper

wire 0·37 mm. in diameter, wound on a tube 9·6 cms. in diameter in one layer and cut at its middle point, to insert the condenser. The primary is 3·64 ms. long, made of wire 0·7 mm. in diameter, wound symmetrically over the middle portion of the secondary circuit in one layer.

In both cases the receiving aerial is identical with the transmitting aerial. Marconi states that these two tunes give good signals over distances of 190 miles.

The invention of the above-described apparatus enabled Marconi, in the summer of 1900, to conduct and exhibit duplex wireless telegraphy by sending and receiving simultaneous messages from one and the same aerial.

The arrangements at the sending and receiving ends were as shown in Fig. 13. At the transmitting end the two transmitters are



Transmitting station. *Receiving station.*

FIG. 13.—Arrangement of Transmitting and Receiving Apparatus in Marconi System of Multiple Syntonic Wireless Telegraphy.

connected to the same aerial wire, and each transmitter is operated independently by its own key. Two sets of waves are, therefore, radiated from the aerial, one which we may call the A wave, and the other the B wave.

At the receiving end two receiving sets are also connected, as shown to one and the same aerial, and when the adjustments are properly made, one of these receivers responds only to the A wave, and the other only to the B wave. Hence the transmitters may be set to work simultaneously, and simultaneous but different messages received on the two transmitters.

6. Transatlantic Wireless Telegraphy.—Marconi's investigations on syntonic telegraphy were essential steps in the accomplishment of his great ambition, viz. long-distance transoceanic wireless telegraphy.

In January, 1901, he established wireless communication on his system between St. Catherine's, in the Isle of Wight, and the Lizard,

in Cornwall, a distance of 200 miles. This was first done on January 23, 1901, the first day of the reign of His Majesty King Edward VII.

The facts were mentioned soon after in an address given by the author to the Liverpool Chamber of Commerce on February 12, 1901, on the application of wireless telegraphy to communication with lightships and lighthouses.[18]

Previously to this, however, in June, 1900, when Mr. Marconi returned from the United States, after having achieved the feat of sending wireless messages over 100 miles, he had arrived at the decision to make a serious attempt to send an electric wave across the Atlantic and detect it on the other side. He had long held in view the application of his system of wireless telegraphy to transatlantic working, not merely as an experimental feat, but with the object of making it a means for commercial communication.

It was obvious, however, that if such a purpose was to be brought to fruition it would necessitate the employment of more powerful electromagnetic waves than those previously used, and it was, above all things, necessary to be perfectly certain that the production of these waves would not prevent or cripple the already established wireless communication between ships and the shore. Moreover, the nature of the plant to be employed required careful consideration.

Up to that date the only appliances used in creating the waves had been ordinary induction coils taking, say, 200 or 300 watts, and giving a 10- or 20-inch spark. At most, therefore, half a horse-power had been the expenditure in electrical wave making. The condensers used had been ordinary Leyden jars, and no difficulty had been found in making and breaking the 15- or 20-ampere primary current of the induction coil, with a heavy Morse key to make the signals. Although Marconi had long since shown that increase in the height of the aerial increased the effective range of signalling, the practicable height of masts for supporting the aerial was considered to be about 200 feet. Hence the conclusion was that transatlantic wireless telegraphy could only be accomplished by the employment of greater electrical wave energy. This, however, necessitated substituting for apparatus of a physical laboratory character, viz. induction coils, Leyden jars, etc., engineering plant much more powerful, yet arranged so as to be safe to use.

Knowing the experience which had been gained by the Author in dealing with extra high-tension alternating currents in electric-lighting work, Mr. Marconi invited his assistance in July, 1900, in specifying the nature of the electrical engineering plant to be used, and also in designing special portions of the apparatus for generating and controlling the powerful electromagnetic waves it was desired to create and use. This involved many experiments on a small scale before embarking on the construction of large and costly plant of an entirely new type.

A convenient site at Poldhu, near Mullion, on the coast of Cornwall, was leased in August, 1900, for the erection of the first electric wave power station, and the construction of appropriate buildings

[18] See *Liverpool Courier* and *Liverpool Journal of Commerce* of February 13, 1901.

was commenced in October, 1900, by the Marconi Wireless Telegraph Company.

In the interests of scientific history, it may be well just to mention briefly the facts and dates connected with the first serious attempt at transatlantic wireless telegraphy. The machinery specified by the Author, after consultation with Mr. Marconi, began to be erected at Poldhu in November, 1900, and Mr. Marconi at the same time decided the nature of the aerial that he proposed to employ. This was to

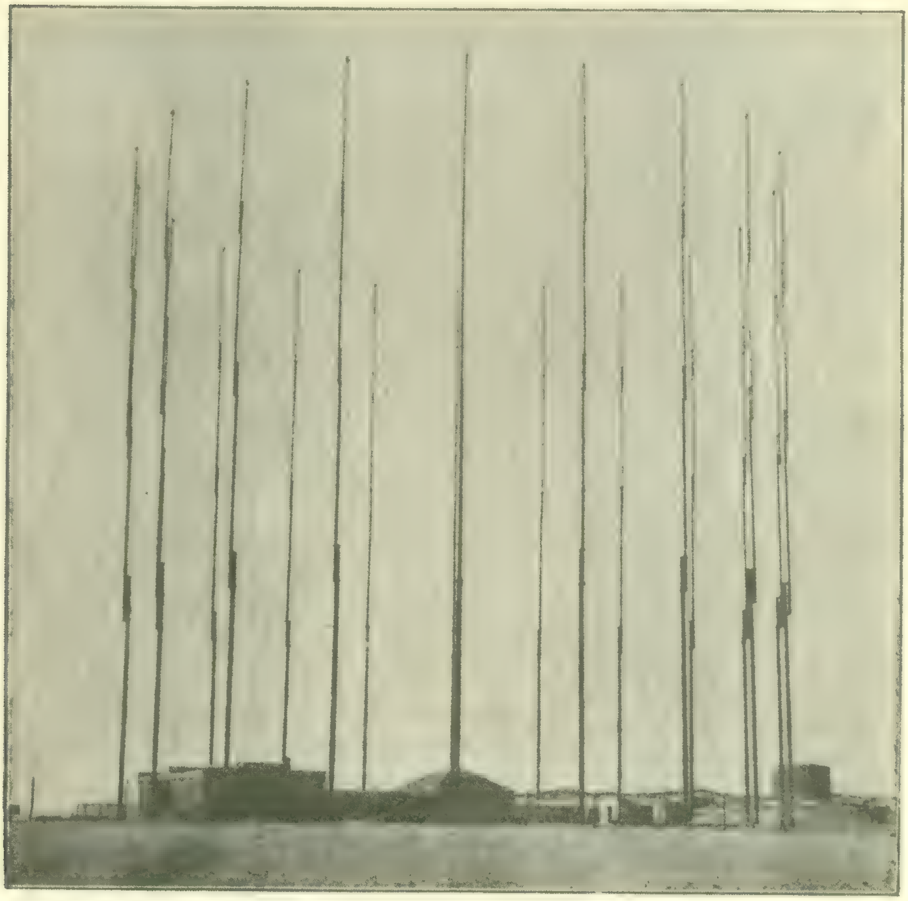


Fig. 14.—Circle of Masts, 200 feet in height, originally erected to sustain the Conical Antenna at the Poldhu and Cape Cod Electric Wave Power Stations in 1901, for Marconi's Transatlantic Wireless Telegraphy.

consist of a ring of 20 masts, each 200 feet high, arranged in a circle 200 feet in diameter, the group of masts supporting a conical arrangement of wires insulated at the top and gathered together at the lower point in the shape of a funnel (see Fig. 14).

In December, 1900, the building work was so far advanced that the writer was able to send down drawings showing the arrangement proposed for the electric plant in the station. This being delivered and erected, experiments were tried by the Author at Poldhu in

January, 1901, for the purpose of ascertaining how far it would be efficient for the purpose in view.

At Easter, 1901, the Author paid a second long visit to the Poldhu station, and, by means of a short temporary aerial, conducted experiments between Poldhu and the Lizard, a distance of 6 miles, which were sufficient to show that the work was being conducted on the right lines.

A view is given in Fig. 15 of the Poldhu station—the first electric wave power station in the world—at this stage of the enterprise.

During the next four months much work was done by Mr. Marconi and the Author together, in modifying and perfecting the wave

From a photograph by the Author.

FIG. 15.—Photograph of the First Buildings erected in 1900 at Poldhu, Cornwall, England, for Experiments on Transatlantic Wireless Telegraphy.

generating arrangements, and numerous telegraphic tests were conducted during the period by Mr. Marconi between Poldhu, in Cornwall, and Crookhaven, in the south of Ireland, and Niton, in the Isle of Wight. A delay occurred owing to a storm on September 18, 1901, wrecking a number of the masts; but sufficient restoration of the aerial was made by the end of November, 1901, to enable Mr. Marconi to contemplate making an experiment across the Atlantic. He left England on November 27, 1901, in ss. *Sardinian*, for Newfoundland, taking with him two assistants—Messrs. Kemp and Paget—and also a number of balloons and kites. He arrived at St. John's, in Newfoundland, about December 5, and made arrangements for sending up a balloon and an attached aerial wire. Having previously instructed his assistants at Poldhu, he cabled on December 9, 1901, to begin a programme consisting in sending the letter "S" (which, on

the Morse alphabet, consists of three successive dots) from 3 p.m. to 6 p.m. each day. Signals began to be sent out in this manner from Poldhu, in Cornwall, on Wednesday, December 11; and after some difficulty in elevating the aerial wire in Newfoundland by means of a kite, Marconi received the "S" signals at St. John's, in Newfoundland, on Thursday, December 12, 1901. On Friday, December 13, he confirmed this result, and on Saturday, December 14, 1901, he was able to cable a message to Major Flood Page, one of the directors of the Marconi Wireless Telegraph Company in London, to this effect:—

"St. John's, Newfoundland, Saturday, December 14, 1901. Signals are being received. Weather makes continuous tests very difficult. One balloon carried away yesterday."

In these experiments the actual power employed in Cornwall for the production of the waves was not more than 10 or 12 kilowatts. The sending aerial consisted of fifty bare stranded copper wires, 7/20 in size, suspended from a triatic stay, strained between two masts 160 feet in height and 200 feet apart. The wires were arranged in a fan shape, and connected together at the bottom by a bar, a common wire being brought from the junction through the roof of the station. With this arrangement, however, electromagnetic waves were produced, which crossed the Atlantic and retained sufficient energy at a distance of 2200 miles to influence the receivers employed by Mr. Marconi.

Full details of his operations on arriving in Newfoundland were given in a communication published in the *Times* of January 3, 1902. On arriving in Newfoundland, Mr. Marconi secured the goodwill and assistance of the Governor, Sir Cavendish Boyle, and also of the Premier, Sir Robert Bond, who offered him every assistance. They placed at his disposal a room in a disused Government building, which occupied a site on a Signal Hill—a lofty eminence overlooking the port of St. John's, Newfoundland (see Fig. 16). This hill is crowned by a plateau, 2 acres in extent, and afforded an ample area for manipulating the kites and balloons. On this site the receiving apparatus was set up, and on Monday, December 9, 1901, Mr. Marconi and his assistants began their work. By Wednesday they had inflated their balloon, and it made its first ascent, carrying with it the aerial wire; but it soon broke away and was lost. On Thursday they succeeded in elevating a kite to a height of 400 feet, which kept an aerial wire attached to it elevated in space.

As the object of these experiments was in the first place to ascertain whether an electric wave generated with any such power as 10 to 25 kilowatts could be made to traverse the Atlantic, and follow round the curvature of the earth, it was obviously out of the question to make the costly permanent arrangements requisite for utilizing the best forms of syntonic receiver.

The aerial wire used consisted of a copper wire 400 feet long, upheld by the kite, which, in the strong wind then prevailing in Newfoundland, was rising and falling irregularly during the experiments. Hence the electrical capacity of the wire was varying, and it was impossible to make use of any form of syntonic apparatus. Marconi was therefore obliged to use the next best means at his disposal.

He hardly expected to obtain in this first attempt, especially with non-syntonic apparatus, oscillations in his temporary receiving aerial sufficiently strong to actuate one of his ordinary receivers, including a nickel filings tube, tapper, and relay, neither was it absolutely necessary to record the signals. He therefore employed a telephone as a receiver, simply connected in series with a coherer of some kind. Those employed consisted of tubes containing loose carbon powder and cobalt filings, and also the form of carbon mercury-iron self-restoring cymoscope already described under the name of the

By permission of the Century Company, New York.

FIG. 16.—Government Building on Signal Hill, St. John's, Newfoundland, in which Mr. Marconi received the First Electric Wave Wireless Telegraphic Signals sent across the Atlantic from Poldhu Power Station in December, 1901.

"Italian Navy coherer." Experience had shown that a tube of the latter kind, although not well adapted for syntonic telegraphy, yet when used in series with a source of small continuous electromotive force, such as a shunted Leclanché cell, and a telephone, was extremely sensitive.[19] On the second day experiments were made to

[19] Assertions were subsequently made that Marconi had achieved the feat of detecting electric waves across the Atlantic by the aid of other inventions than his own. As the object of these first experiments was to discover if the waves could be detected at all, he naturally made use of the most appropriate means known to him. The use of a telephone as a means of detecting small but sudden changes in the resistance of a microphonic or imperfect contact was already well known, and there was no reason why he should not have employed it if convenient.

In a discourse delivered subsequently at the Royal Institution, June 13, 1902,

ascertain if intelligible messages could be sent, but the difficulties of maintaining the temporary aerial elevated by a kite at the precise times, when the waves, by preconcerted arrangement, were being sent, rendered the few signals so received indistinct.

Nevertheless, it had been demonstrated that an electric wave generated by no inordinate power could traverse the Atlantic and retain sufficient energy at that distance to affect a telegraphic wave-detecting device. This achievement created an immense sensation in every part of the civilized world.

These profoundly interesting experiments were, however, brought to an untimely end by the action of the Anglo-American Telegraph Company, who had a monopoly of receiving in Newfoundland trans-atlantic messages until April 15, 1904. They entered a peremptory demand for these experiments to cease, and although this was generally regarded as a tactical mistake on their part, Mr. Marconi complied and removed his apparatus.[20]

The experiments, however brief, demonstrated to Mr. Marconi, his colleagues, and co-directors, that if permanent aerials and appropriate power stations were erected on the coasts of Great Britain and the United States, electric wave wireless telegraphy between them was fully practicable.

7. Long-distance Wireless Telegraphy, 1902–1907.—Returning to England in February, 1902, Marconi made arrangements for the erection at Poldhu of a permanent structure for carrying a large aerial. This consisted of four wooden lattice towers, each 210 feet high, placed at the corners of a square 200 feet inside. These structures were designed and erected under the superintendence of Mr. A. E. Heming, one of the Marconi Company's engineers. They were strongly stayed by wire ropes, and surrounded by stairways for ascending to the top (see Fig. 17 and *Frontispiece*). The towers carried insulated rope triatic stays, from which was suspended a conical arrangement of four hundred copper wires forming the aerial, put up in sections so that more or less could be employed. The buildings for the generating plant were placed in the middle of the area. Additional machinery was obtained, and improvements carried out which had been indicated by experience.

At the same time similar towers and stations were erected at Cape Cod in Massachusetts, U.S.A., and at Cape Breton in Nova Scotia.

Mr. Marconi devoted himself with immense energy and perseverance to the work of further improving the sending and receiving apparatus. In much of the work the author was confidentially consulted and assisted in specifying the plant and devising new appliances for creating and controlling the electric oscillations generated. In February, 1902, Marconi returned to Canada, and on the way across the Atlantic conducted interesting experiments on

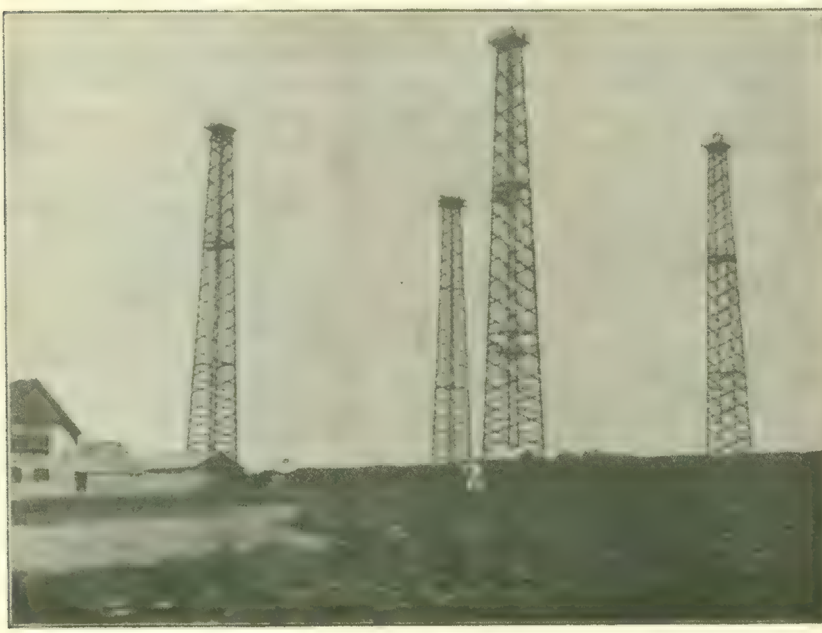
"On the Progress of Space Telegraphy," Mr. Marconi described in detail the methods he had employed, and made acknowledgment of the assistance he had received from all those who had aided him in the design and working of the appliances employed. See *The Electrician*, 1902, vol. 49, p. 392; and also the *Proceedings of the Royal Institution*, 1902, vol. xvii. p. 208.

[20] See the *Times* of January 3, 1902, and contemporary newspapers for details of this controversy and incident.

board the American liner the ss. *Philadelphia.* An insulated aerial wire 60 metres high was fixed to the ship's masts. Messages sent from Poldhu were received on board as the vessel went west and printed down on the Morse tape. Readable messages were obtained in this way up to 1551 miles from Cornwall, and indications or signals up to 2099 miles, by the aid of the Marconi receivers already described.

A fact of considerable interest observed on this voyage was that the signals could be received at a greater distance by night than by day. They ceased entirely at 700 miles distance by day, but were detectable up to 1551 miles by night. We shall make further reference to the probable reason for this difference in Chap. IX.

In July, 1902, Marconi conducted similar experiments on board



From a photograph by the Author.

FIG. 17.—Lattice Towers erected at Poldhu, Cornwall, England, to carry the Antenna Wires for the Marconi Electric Wave Power Station.

the Italian warship *Carlo Alberto,* generously placed at his disposal for this purpose by the Italian Government, on a voyage from England to Cronstadt, and on this occasion he employed his magnetic detector as a receiving instrument (see Chap. VI. p. 449), the invention of which had occupied him for some long time previously.

On July 7, 1902, the *Carlo Alberto* left Dover for the Baltic, having been equipped with an arrangement of aerial wires and with receiving apparatus. Messages were received on board from Poldhu as far as Cape Skagen, in Denmark (800 or 900 miles), and (July 15) at Cronstadt (1500 miles).

In these experiments a considerable part of the great circle line between the sender and receiver lay over land.

In August, 1902, the *Carlo Alberto* proceeded to the Mediterranean,

continuing to receive wireless messages from Poldhu on the way.

On September 11, 1902, the managing director of the Marconi Wireless Telegraph Company, was able to announce in a letter to the *Times*, that the *Carlo Alberto*, which left England on August 23, had reached Spezia (Italy), and had been in constant communication, by electric wave telegraphy, with Poldhu during the voyage. Perfect messages were received in Gibraltar Harbour and throughout the Mediterranean voyage. Telegrams for the King of Italy and the Italian Minister of Marine were received from Poldhu and printed on Morse tape in Spezia Harbour. A glance at the map shows that the electric waves in this case must have crossed the Bay of Biscay, Spain, France, and the Alps. Subsequently the *Carlo Alberto* was placed at the disposal of Mr. Marconi by the Italian Minister of Marine for the purpose of additional tests across the Atlantic.

The *Carlo Alberto* sailed from Plymouth with this object on October 20, 1902, for Sidney, Nova Scotia. She was fitted especially for this voyage with gaffs, by which antenna wires could be elevated 25 metres above the trucks of the spars forming her normal rig (see Figs. 18 and 19). Between these spars on the main and fore masts was slung an insulated stay, from which 50 copper wires, forming the aerial, were suspended. The operating room was built round the after conning tower. Messages were received from Poldhu during the voyage and whilst the ship was lying in Sidney Harbour.

Towards the end of 1902 the structures erected at the Nova Scotia and Cape Cod stations to carry the great aerials were sufficiently advanced to enable preliminary tests to be undertaken. On December 21, 1902, Marconi was able to send the following message to England from Glace Bay, Nova Scotia:—

"I beg to inform you that I have established wireless telegraphic communication between Cape Breton, Canada, and Poldhu, in Cornwall, England, with complete success. Inauguratory messages, including one from the Governor-General of Canada to King Edward VII., have already been transmitted (December 21) and forwarded to the Kings of England and Italy."

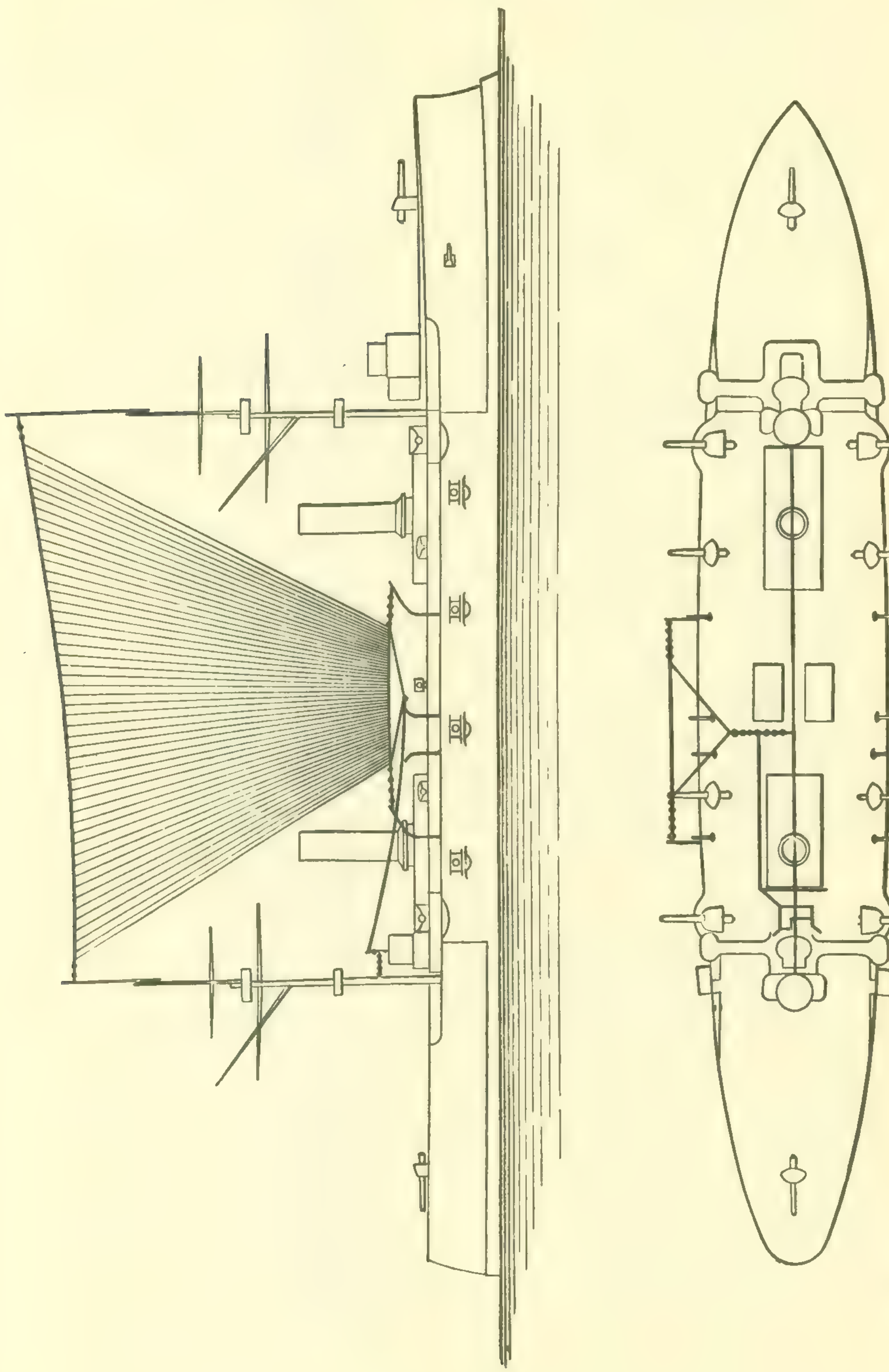
Following this announcement came the news that on January 19, 1903, a wireless message was transmitted across the Atlantic from Wellfleet, Cape Cod, Massachusetts, U.S.A., to Poldhu, Cornwall, England, from Mr. Roosevelt, President of the United States, to King Edward VII., as follows:—

"To His Majesty King Edward VII., London.

"In taking advantage of the wonderful triumph of scientific research and ingenuity which has been achieved in perfecting the system of wireless telegraphy, I extend on behalf of the American people the most cordial greetings and good wishes to you and all the people of the British Empire."

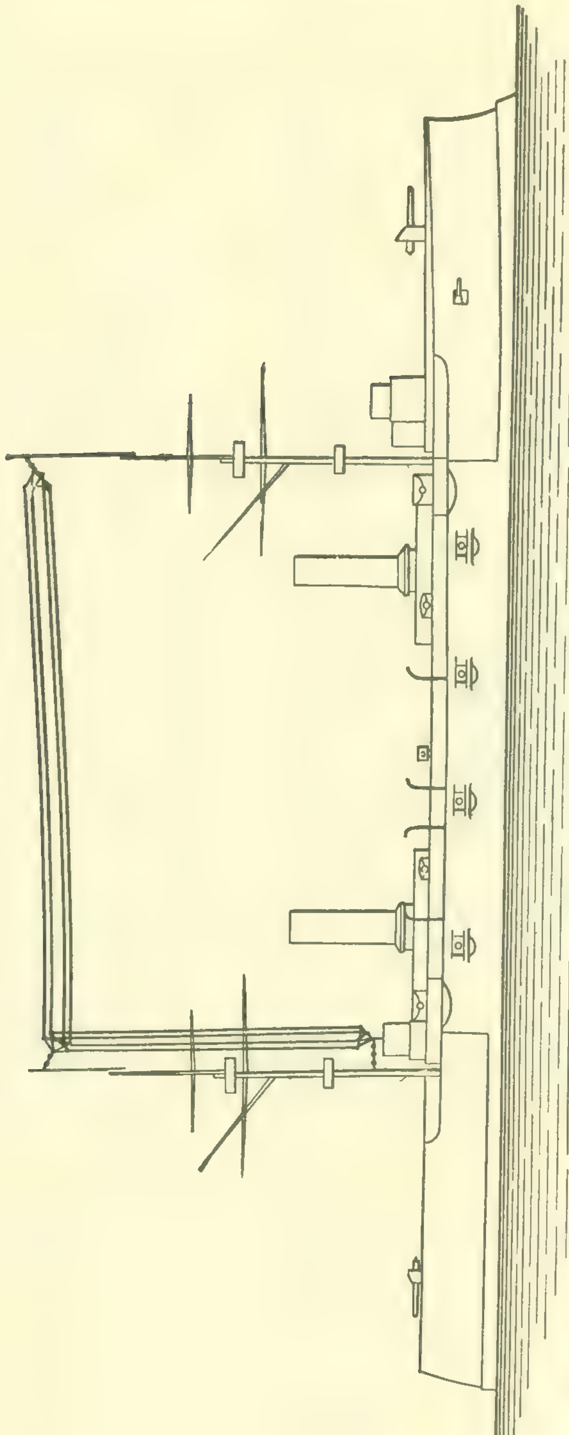
The electromagnetic waves conveying this message travelled 3000 miles over the Atlantic, following round an arc of 45° on a great circle, and were detected telephonically by the Marconi magnetic receiver at Poldhu.

In the next few months a large number of messages were sent in this manner in both directions across the Atlantic. In April some news messages were transmitted to the *Times*, but the service was



From "The Electrician."

FIG. 18.—View of the Italian Battleship *Carlo Alberto*, showing the Arrangement of Antenna Wires used during Mr. Marconi's Voyages in the Baltic and Mediterranean Seas.



From "The Electrician."

FIG. 19.—Another Arrangement of Antenna Wires employed on the *Carlo Alberto* for Wireless Telegraphic Work on Mr. Marconi's Voyages.

interrupted by breakdown of a portion of the transmitting appliances in the stations on the American side. It is not necessary to devote space to discussing the causes of these delays in the fulfilment of the expectations which had been raised as to the speedy establishment of regular wireless telegraphy across the Atlantic.

The history of transatlantic wireless telegraphy has so far followed very much on the lines of the history of submarine cable Atlantic telegraphy. It will be remembered that the first attempt to lay a cable across the Atlantic in August, 1857, was a failure. In 1858 a cable was laid successfully, but it broke down after a life of three months, when about 700 messages had passed through it. From that date there was an interval of nearly seven years before means and resolution were forthcoming to make a fresh attempt. A third effort was made in 1865, but it was only in 1866, or nine years after the first expedition, that a cable was laid which established uninterrupted commericial communication.[21]

Hence, although those interested in the submarine cable industry have not been slow to announce their belief that wireless transoceanic telegraphy can never be brought to a condition to compete with cables from a commercial point of view, impartial students of the history of electrical technology will hesitate before endorsing this opinion.

We have only to glance backwards at the early history of submarine cable telegraphy itself, electric telephony, or electric lighting, to see that when there is a substantial scientific achievement on which to work, technical skill and commercial enterprise have a foundation on which a superstructure of commercial success may be subsequently erected, even although preliminary failures and great initial difficulties have to be faced. The facts which were established beyond question by the end of 1902 were, that telegraphic messages could be sent 3000 miles across the Atlantic by electromagnetic waves, at a speed and with a certainty which is not in any degree inferior to that effected by ordinary submarine cable telegraphy, when employing single transmission and hand sending.

This was done in little more than six years from the date of Marconi's first public exhibition of electric wave wireless telegraphy in Great Britain, conducted over a maximum distance of only *two* miles. In view of this fact, he will be a bold prophet who will venture to affirm what may not be done in six years more.

It is useless, however, to expend time in speculating whether transoceanic wireless telegraphy is destined to affect the traffic through cables. The history of past competitions of an analogous kind shows that they will probably coexist. When the news came to England in 1878 that Edison had succeeded in making a practical incandescent electric lamp, a serious fall in gas shares occurred. The public jumped to the conclusion that the new electric light would kill gas. It took fifteen years for the use of the incandescent lamp to make any impression at all on private gas lighting; and subsequent improvements in gas burners have resulted in more gas being used now than before the advent of electric lighting.

The public in the same manner flung their cable shares on the

[21] See "The Story of the Atlantic Cable," by Mr. Charles Bright. Newnes & Co. London, 1903.

market in the spring of 1902, in the belief that the wireless telegraphy would immediately replace the present submarine cable telegraphy, and sensational newspaper announcements assisted the depression.

On the other hand, experience shows that it is unwise to prophesy failure for any technical enterprise which has a real basis of scientific fact beneath it. It has been demonstrated that ordinary code and commercial messages can be transmitted across the Atlantic by electromagnetic waves, but outstanding questions of speed, cost, certainty, and privacy must await decision by the resistless arbitrament of facts and events. There is no question, however, that long-distance electromagnetic wave telegraphy has come to stay, and will not only stay, but continue to advance.

One important matter, however, was completely settled in 1903, viz. that the power-station working could be conducted without any interference with the ship-to shore or ship-to-ship wireless telegraphy. Statements having been made in some technical journals to the effect that the establishment of power stations for the production of electromagnetic radiation suitable for long-distance telegraphy would render it impossible to conduct the highly necessary ship-to shore communication, the author had the opportunity afforded to him by Mr. Marconi, in March, 1903, of putting this contention to crucial test.

There is at Poldhu a mast and aerial removed by 100 yards or so from the aerial of the power station. Six miles away, at the Lizard, there is a Marconi station in connection with Lloyd's, for communication with vessels proceeding up and down the Channel which are equipped with Marconi apparatus. It was arranged that at a certain time wireless messages should be sent off simultaneously from the power station and from an ordinary ship equipment in connection with the isolated mast at Poldhu, and received on two Marconi receivers connected to the aerial at the Lizard. These experiments took place on March 18, 1903, under the direction of the author, and different written messages were handed in to the sending operators at the power station and neighbouring small or ship station, the operators not knowing a moment before the message that would be given to them. Some of these messages were in cypher and some of a commercial character. For example, the following cypher message was despatched in Morse code from the power station :—

"Bulfish, London. Streamlet Solstice Turtle. Worthily, John Brown, Captain."

Simultaneously the following was despatched from the small station 100 yards away, viz. :—

"A thick fog prevails here. SS. *Mignonette* has been run down by a foreign ship. Send tugs immediately."

At the Lizard station all these messages were received by Mr. Marconi and printed on Morse slip, pair and pair simultaneously on two independent Marconi receivers attached to the same aerial. In no case was any mistake made. To be sure that the power station was sending out waves much more powerful than those of the small station, other receivers were placed at Poole, 200 miles away, and the

messages from the power station alone were recorded there. These were telegraphed back for verification by postal telegraph immediately on arrival.

The author described these results and exhibited the messages as sent and as received a few days afterwards at a Cantor lecture at the Society of Arts.[22]

The tests were confirmed some months later by Admiralty officials. Mr. Marconi went to Gibraltar on board the British battleship *Duncan*, then under command of Captain (now Admiral Sir) H. B. Jackson, and during the voyage similar experiments were undertaken. During the stay of the *Duncan* at Gibraltar wireless messages were received from Poldhu, including one official communication. The tests were watched on board H.M.S. *Duncan* by Admiral Jackson, and at the Poldhu station by Lieutenant F. G. Loring, R.N. It was definitely ascertained that the short-distance Marconi apparatus supplied to the Admiralty for ordinary naval use was not affected by the action of the electromagnetic waves sent out from the power station at Poldhu.

These proofs and experiences enabled Mr. Marconi shortly afterwards to establish a regular system of news transmission from Poldhu to Atlantic liners *en voyage*.

Small newspapers are now published on board the Atlantic liners daily which contain news paragraphs received during the previous night from the power station on the mainland. The inauguration of this enterprise took place on the Cunard liner *Campania* in June, 1904, when Mr. Marconi kept the vessel during the entire voyage in receipt of communications either from Poldhu, in Cornwall, England, or the station at Cape Breton, in Nova Scotia, or that at Cape Cod, near Boston, U.S.A. The longest distance covered by a message on that occasion was one sent from Poldhu, received on board the *Campania* when 2250 miles from England. It was a message of thirty words relating to the submersion test of an American submarine boat. The daily paper published on board is entitled the *Cunard Daily Bulletin*. A representation of a page of it is shown in Fig. 20 (see p. 554).

By the end of 1909 the Marconi Wireless Telegraph Company had equipped more than 300 ships with the apparatus for wireless communication with each other and with coast stations. These included the principal passenger steamships of the Cunard, White Star, Norddeutscher Lloyd, Allan, American, Red Star, and Atlantic Transport and other British and Foreign Companies. Also vessels belonging to the Compagnie Transatlantique, Belgian Mail Packet, and Isle of Man Steam Packet Companies.

It has become an indispensable method for conducting naval signalling, and the use made of it in the Russo-Japanese war showed it to be a most important element in controlling naval tactics, so much so that the principal naval powers in the world were compelled to make it the subject of legislative control within the limits of their respective territorial authority.

During the siege of Port Arthur, the *Times* newspaper, with great

[22] See also a long letter from the author describing these tests, published in the *Times* for April 14, 1903.

enterprise, established ship and shore stations, and equipped them with apparatus for wireless telegraphy supplied by an American (The

CUNARD DAILY BULLETIN.

MARCONIGRAMS

DIRECT TO THE SHIP.

EDITORIAL OFFICE

R.M.S. "CAMPANIA."

Monday, June 6th, 1904, 1·00 p.m,

Received from the Marconi Station at Poldhu (England), 800 miles distant.

WAR NEWS.

According to a report from Admiral Togo Wireless Telegraph Stations have been erected on the promontory of Liau-ti-Shan.

Explosions occurred at Port Arthur on Saturday, from which it is inferred that new batteries are being prepared.

News has been received in Paris that the Russian Army Corps is executing a forced march southwards, having received urgent orders to re-occupy Liau-Tung Peninsula and relieve Port Arthur.

TIBET EXPEDITION.

The Tibet Expedition has captured two of the enemy's guns, and there is a report current that a Lhasa General has been killed.

AMERICAN NEWS.

A distillery at Peoria, Illinois, which is considered to be the second largest in the world, has been destroyed by explosions and fire, causing the death of ten persons.

STOP-PRESS.

WAR NEWS.
Russian Disaster.

Telegrams to hand state that Admiral Togo reports a further encounter, during which a Russian Gunboat was torpedoed and sunk in the vicinity of Port Arthur thus still further reducing the Russian fleet available in Eastern Waters.

Tuesday 2. a.m.

Communication was established and the following news received from Marconi Station, Cape Breton, (Canada), when the "Campania" was 2000 miles from New York.

ICEBERGS,

According to reports which continue to come to hand, more icebergs than usual have been sighted in the Atlantic, the steamer "Island" from Copenhagen for New York, in particular, reports having passed ten.

The Compagnie Generale Transatlantique "La Lorraine" reports icebergs in latitude forty forty-five to forty-two thirty longitude forty-eight twenty-seven to fifty fifty-four.

DEATH OF PRINCESS MARY OF HANOVER.

Telegrams to hand indicate that the death of Princess Mary of Hanover on Saturday last, has caused universal sorrow.

THE TIBET EXPEDITION.

Telegrams received confirm that the British have Captured two twenty-four pounders and killed a Lhasa General.

FINANCIAL NEWS.

Stocks dull generally and prices remain unchanged.

By kind permission of the Marconi Wireless Telegraph Company, Ltd.

FIG. 20.—Facsimile of a Page of the *Cunard Daily Bulletin*, published on board the Cunard Liners, containing Marconigrams sent by Wireless Telegraphy.

De Forest) Company. This proved to be a valuable means for securing early and authentic news from the seat of war.

It was the first, and probably will be the last, time that the

opportunity occurred for such an employment of wireless telegraphy.[23]

8. Marconi's Transatlantic Wireless Telegraphy.—Although the transmission of wireless messages between the station at Poldhu in Cornwall, England, and that at Cape Cod in Massachusetts, U.S.A., in 1902, had sufficiently proved the practicability of transatlantic radiotelegraphy, it was considered advisable by Mr. Marconi and his co-directors of the Marconi Wireless Telegraph Company to defer the attempt to conduct regular intercommunication until the completion of two new large radiotelegraphic stations, one placed at Glace Bay in Nova Scotia and the other at Clifden in Connemara, Ireland. These stations were sufficiently advanced by the middle of 1907 to admit of telegraphic work being inaugurated on October 17, 1907, and a limited service of press messages was undertaken. On February 3, 1908, the service was extended to ordinary messages between London and Montreal, the transatlantic rates proper being 2½*d.* for press and 5*d.* for ordinary messages. The evidence of the press using this Marconi wireless transatlantic service, such for instance as that of the *New York Times* and the London *Times*, was that its efficiency and promptness were in every way satisfactory.

Even then, however, the condition of permanent service had not been reached. A disastrous fire occurred in August, 1909, at the Nova Scotia station, and destroyed part of the plant, and it was not until the month of April, 1910, that the transatlantic wireless service for public use was again re-established.

How far such a supermarine wireless communication is capable of taking the place or even rivalling submarine cable communication for all purposes is not a question which can be decided by *à priori* arguments. Time alone will show. Nevertheless, the extraordinary rapidity with which this new method of intercommunication has been developed, and the relatively small capital outlay involved in it, make its progress a fact of the greatest importance in connection with the growing demands of the world for cheaper and more easily established methods of oversea intercommunication. Transatlantic wireless telegraphy by Hertzian waves is, however, now an accomplished fact, and in the only form in which it is yet practically available (1910) it is unquestionably the result of the indomitable perseverance and inventive ability of Mr. Marconi, aided by those whose faith in the possibilities of the enterprise have given him the necessary financial and technical support. Further details of the appliances used in these long distance stations are given in Chap. XI. on radiotelegraphic stations.

9. Supermarine Wireless Communication.—The complete establishment of radiotelegraphic communication between ships equipped with the necessary apparatus and shore stations enabled the Marconi Company to develop a form of oceanic wireless exchange between hundreds of vessels and the shore – such that no ship furnished with their apparatus was ever out of communication with its home ports. The enormous value of this system was on many

[23] Full details of the enterprise were given by Captain Lionel James, war correspondent for the *Times*, in a paper read to the Society of Arts, January 18, 1905.

occasions amply demonstrated. On January 23, 1909, the ss. *Republic*, a White Star liner, collided with the ss. *Florida* in the Atlantic, and in the absence of any means of securing help the passengers, crew and ship would in all probability have been lost. Fortunately, the ss. *Republic* had the Marconi wireless apparatus installed, and the operator, Mr. J. R. Binns, was able to establish communication with the Marconi shore station at Sias-conset, on Nantucket Island, and this station signalled the ss. *Baltic*, the ss. *La Lorraine*, and numerous other vessels, so that shortly seven vessels were on their way to give their aid. The captain of the *Baltic* was able to reach the injured vessel in time and rescue all those on board. A similar service was rendered in the case of the ss. *Slavonia* on June 10, 1909, which stranded on Flores Island, in the Azores. The signals brought the *Batavia*, 150 miles away, and the *Prinzessin Irene* to the aid of the *Slavonia*, and the 410 passengers and crew were taken off without the loss of a single life. The system, however, provides not merely a safeguard of unspeakable value in the case of accident, but the means by which messages can be transmitted from any British postal telegraph office to ships on the high seas within certain times and range. The exact time of sailing from port of the vessels fitted with the wireless apparatus being known, their position on the high seas with respect to certain shore radiotelegraphic stations at subsequent dates and times is also known, and can be ascertained from a communication chart issued by the Marconi Company. Messages can be sent to that vessel if within reach of any shore station or sent from other intermediate vessels if too far to be reached directly.

10. Contributions to Radiotelegraphy by Other Workers.—Whilst Marconi was thus successfully engaged in developing wireless telegraphy along lines which had removed it out of the region of unfruitful experiment into a condition of the greatest practical utility, other inventors began to make contributions to the subject which must be mentioned.

Sir Oliver Lodge, who had made the subject of electric oscillations and electromagnetic waves a special study, turned his attention in 1897 to the application of this knowledge to electric wave telegraphy, and later on associated himself with Dr. A. Muirhead, well known for his inventions in telegraphy, in developing radiotelegraphy.

In Germany, Prof. A. Slaby, of Charlottenburg, Count Arco, Prof. F. Braun, of Strasburg, Dr. J. Zenneck, of Brunswick, and many others began to cultivate the same field of research. Many other scientific workers, such as P. Drude, M. Abraham, M. Wien, E. Aschinass, G. Seibt, W. Schloemilch, and J. Dönitz, in Germany; Profs. Poincaré and Branly and MM. Blondel, Tissot, Ferrié, Ducretet and Turpain, in France; Prof. Righi and MM. Bellini and Tosi and Artom, in Italy; Prof. Popoff, in Russia; Mr. V. Poulsen, in Denmark; Profs. Trowbridge, G. W. Pierce, R. A. Fessenden, and Messrs. L. de Forest and J. J. Stone, in the United States, have made contributions of importance either to the theory or practice of radiotelegraphy.

In England, in addition to Mr. Marconi and his associates, including the author, Sir Oliver Lodge, Dr. Muirhead, Mr. Duddell,

and many others have contributed to the scientific or inventional side of the subject.

The officials of the British Postal Telegraph Service and British naval officers have carried on their own investigations on it.

In justice to English workers, it should be noticed that one of the earliest British patent applications for improvements in means for telegraphing or telephoning without wires was made by Mr. A. C. Brown and Mr. G. R. Neilson, who are both connected with the great submarine cable industry. These inventors filed their provisional specification, No. 28,955, on December 17, 1896, subsequently to the date of application of Marconi's first British patent, but previously to the filing of his corresponding complete specification. In this specification Brown and Neilson proposed to place a Hertzian wave oscillator in a box and project a beam of electric radiation into a receiver circuit at a distance which is to be "open or closed and preferably syntonized as nearly as possible to the generating circuit." One feature of interest in this specification is that they suggested the employment of a coherer containing "preferably, but not necessarily, carbon granules," used in series with a voltaic cell and telephone as an electric wave detector. They state that such a carbon coherer is self-restoring, or, at most, needs a few taps by hand at intervals to keep it in order.[24]

It is singular that the two patentees above named should have so nearly anticipated the type of detector afterwards used in conjunction with his aerial and earth connection by Marconi to read the first signals transmitted across the Atlantic. This patent specification of Brown and Neilson in many ways showed remarkable knowledge of the subject of Hertzian waves and their detection, but the patentees did not realize the fundamental importance of the antennæ and earth connections, as the absolutely essential appliances for electric wave wireless telegraphy.

We shall proceed to notice briefly some of these inventions, and to sketch out the chief contributions made by various workers to the evolution of electric wave telegraphy, and in later chapters discuss more in detail the modern appliances for conducting it and the working of radiotelegraphic stations.

11. The Work of Lodge and Muirhead.—Lodge's work on electromagnetic waves developed out of his investigations on electric oscillations and lightning discharges in connection with the protection of buildings from lightning.[25]

He discovered in 1889 that two metallic surfaces in imperfect but not conducting contact were welded together when an electric discharge passed between them,[26] and later on studied the propagation of electric waves along wires.[27] He thus came into close contact with the

[24] In view of the claims made subsequently by many other persons for priority in the use of the so-called telephonic method of reception, this specification of Brown and Neilson is worthy of notice.

[25] See "Lightning and Lightning Guards" (Whittaker & Co); also "On Lightning, Lightning Conductors, and Lightning Protectors," by Sir Oliver Lodge, *Journ. Inst. Elec. Eng.*, 1889, vol. 18, p. 386.

[26] See a paper on "Lightning Guards for Telegraphic Purposes," by Sir Oliver Lodge, *Journ. Inst. Elec. Eng.*, 1890, vol. 19, p. 352; also "The History of the Coherer Principle," *The Electrician*, November 12, 1897, vol. 40, p. 88.

[27] See Sir Oliver Lodge, "On the Theory of Lightning Conductors," *Phil. Mag.*, August, 1888, ser. v. vol. 26, p. 217, or *The Electrician*, August 10, 1888, vol. 21, p. 435.

researches of Hertz on the creation of electromagnetic waves in free space, and this work he both expounded and extended. Reference has already been made to his Royal Institution Lecture in 1894 on the "Work of Hertz and Some of his Successors."

His interest in these matters was, however, scientific rather than technical, and he himself has admitted that before the matter had received attention from others it had not occurred to him to suggest the employment of Hertzian waves for telegraphic purposes. In the course of his scientific work he had directed much attention to the phenomena of electric resonance. Hence, when once it had been indicated that the chief practical importance of Hertzian waves might lie in their application to space telegraphy, Lodge was not slow to apply to it his knowledge of this subject.

Before the date of Marconi's first patent application, Lodge had been occupied with the problem of space or wireless telegraphy by means of electromagnetic induction between two circuits at a distance, bringing to bear on it his acquaintance with the facts of syntony and resonance. As we are not concerned in this book with methods of space telegraphy other than that effected by true electromagnetic waves, we shall not enter into details of Lodge's work on magnetic inductive telegraphy in the field so long cultivated by Sir William Preece.[28]

At the beginning of 1897, owing to the announcements which had then appeared of the results obtained by Marconi, it became clear that electric wave telegraphy had unquestionable advantages over all previously tried methods, and scientific as well as public attention became concentrated on it.

On May 10, 1897, Lodge applied for a provisional patent protection in Great Britain (No. 11,575 of 1897) for "Improvements in Syntonized Telegraphy without Line Wires," and in this document he states that the object of this invention was to enable an operator to transmit messages across space to any one or more of a number of different individuals in various localities, each of whom is provided with a suitably arranged receiver. The subject-matter of the specification deals exclusively with the utilization of electromagnetic waves.

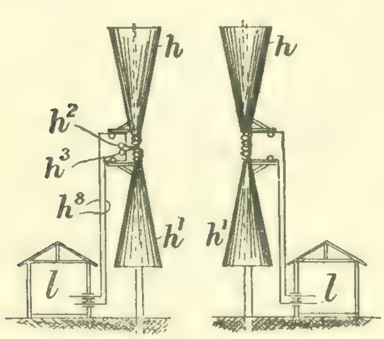


FIG. 21.—Lodge's Wing-shaped Antennæ for Electric Wave Telegraphy.

His radiator was described as consisting of a pair of "capacity areas," or triangular-shaped metal plates, h, h' (see Fig. 21), separated by a spark gap, but having an inductance coil, generally shown as a spiral of a few turns, interposed. In some cases this radiator was to be used horizontally, and in other cases vertically. In this last case the lower metal wing or area might be connected to the earth, or partly buried in the earth, and the upper wing extended by connection to an insulated plate.

[28] See a paper by Sir Oliver Lodge, "Improvements in Magnetic Space Telegraphy," *Journ. Inst. Elec. Eng.*, 1898, vol. 27, p. 799.

Lodge asserted that this form of radiator was capable of persistent or long-sustained oscillations, suitable, therefore, for effecting syntonic telegraphy. He was well aware, and states (*loc. cit.*, p. 2, line 53), that unless the radiator provides these sustained trains of waves, no true syntonic action is possible. A part of the specification is taken up with descriptions of methods of charging electrically these oscillators. The receiving arrangement was to consist of a pair of capacity areas (one of which might be the earth) similar to the transmitter, but containing in its circuit a Branly coherer, consisting of a tube of metallic filings with a "clock, or a tuning fork, or a cog wheel, or other device" mounted on the stand of the coherer to cause a tremor of sufficient intensity. This vibrator or decoherer was evidently to be maintained continuously in action. In some cases the coherer was inserted in the secondary circuit of "a species of transformer," the primary of which was in the circuit of the collecting wings, but no detailed instructions are given for making this oscillation transformer or properly relating the lengths of its circuit and its turns to the capacity and inductances of the collecting circuit. Without this adjustment the oscillation transformer is a detriment rather than an advantage.

Sir Oliver Lodge and Dr. A. Muirhead, the latter well known for his inventions in connection with submarine cable telegraphy, then joined themselves as co-patentees of other inventions in wireless telegraphy, and took out a British patent, No. 16,405 of July 10, 1897. This specification contains a description of numerous devices for causing the coherer or light metallic contact to be decohered by the current which passes through it from the local cell when the electric waves improve the contact. In one of these arrangements a siphon recorder is used as the telegraphic recorder, and the metallic contact is connected by a thread, p, with the recorder coil d, so that a movement of the coil jerks open the contact c (see Fig. 22). In another case the passage of the local current through the contact is made to impart a decohering jerk by the movement either of one of the cohering surfaces or else of a separate piece of metal attached to them, in a strong magnetic field. Broadly speaking, this specification covers devices for decohering a single point contact sensitive to electric waves. A third British specification by the same patentees, No. 18,644 of August 11, 1897, covers a variety of devices intended to give greater certainty of action. The inventors still adhere to the single-point coherer, but join two or more such contacts in parallel if necessary, applying to them vibrations created by clockworked cams or cylinders to keep

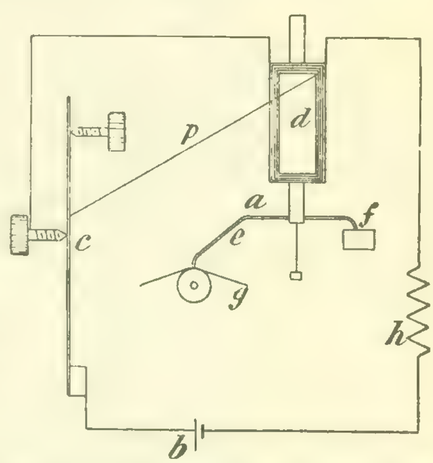


FIG. 22.—Lodge and Muirhead's Combination of Siphon Recorder and Point Coherer.

them in a sensitive condition. In fact, Lodge's method of using the coherer may be said to be, to keep it perpetually in a state of tremor or vibration, whereas the method adopted by Marconi is to apply a carefully regulated set of taps to decohere *after* the coherence has taken place. This specification of Lodge and Muirhead describes also a method of telegraphing by electric waves sent along a bare wire laid on the earth's surface.

A fourth British specification, No. 29,069 of December 8, 1897, by Lodge and Muirhead, is for "Improvements in Syntonic Telegraphy." The inventors introduce a large condenser, *a*, in series with the inductance coil *d* and capacity areas *b*, *c*, and join up the single- or multiple-point coherer, *e*, as a shunt across both inductances and condensers, whilst the local cell, *f*, and telegraphic instrument, *g*, viz. a Kelvin siphon recorder, is joined as a shunt across the condenser alone (see Fig. 23). In some cases they use the earth as one of the capacity areas. The same specification includes a description of an elaborate revolving commutator for changing the positions of the coherer and recording telegraphic instrument, so that each is in turn in the most favourable position in the oscillatory circuit. The author is not aware that any of these receivers or transmitters, with these wing-shaped capacity areas, have ever been employed in practical syntonic electric wave telegraphy.

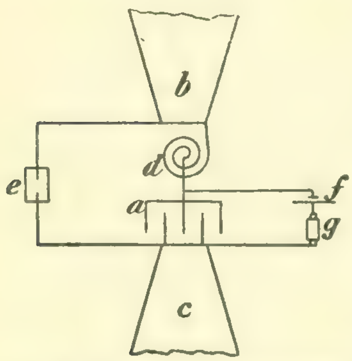
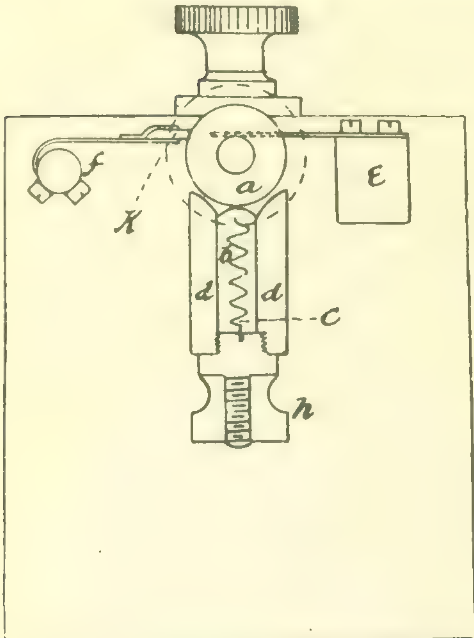


FIG. 23.—Lodge and Muirhead's Method of connecting the Coherer and Telegraphic Instrument to the Wing Antennæ.

Passing over an interval of time, we find that Lodge, Muirhead, and Robinson devised the self-restoring coherer, consisting of a rotating steel disc in contact with an oil-covered mercury surface, which has already been described (Chap. VI. § 6).[29] This coherer they employed to actuate directly a siphon recorder without the intervention of any relay, using a fraction of a volt (generally from 0·1 to 0·3 volt) obtained from a shunted voltaic cell as a working electromotive force. The device is arranged in a compact form, the steel disc lightly touching the oil-covered mercury surface, being revolved continuously by clockwork (see Fig. 24).

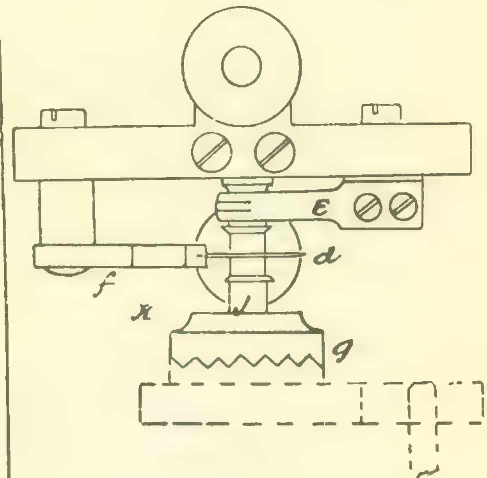
Lodge and Muirhead associated this self-restoring coherer with a receiving circuit and receiving aerial adjusted to have a definite time period of oscillation. For the transmitting arrangement they subsequently adopted a closed oscillation circuit consisting of a condenser, *l*, adjustable inductance, *m*, and spark ball discharger, *g*, in series, the condenser being charged by an induction coil, *c*, and discharging across the spark gap with oscillations. To this closed circuit an aerial wire, *f*, is directly coupled, and some other point on the closed oscillation circuit is connected to the earth, generally through a condenser, *n*, of large capacity. The arrangements of the

[29] See British Patent Specification, No. 13,521 of June 14, 1902, of Lodge, Muirhead, and Robinson.

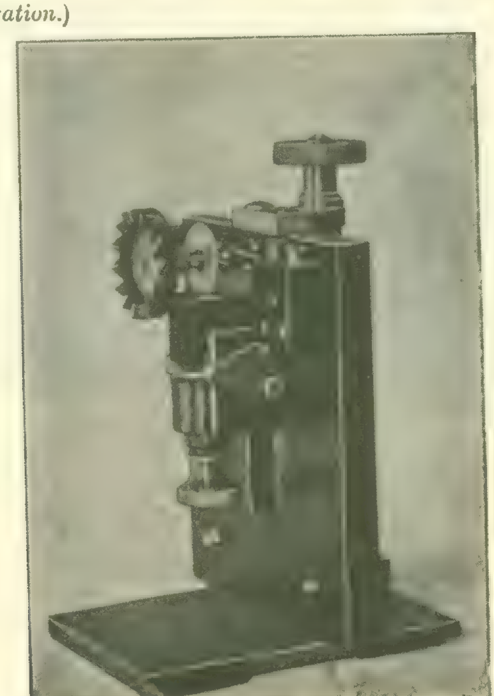


From "Page's Weekly Magazine."

(*Elevation.*)



(*Plan.*)



From "The Electrician."

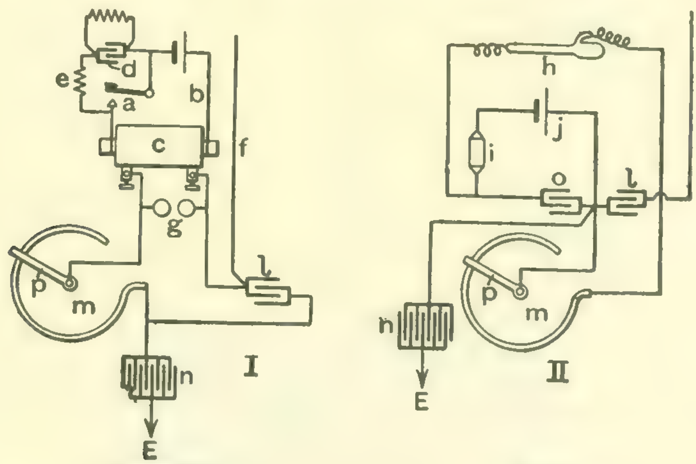
(*Perspective view.*)

FIG. 24.—Lodge-Muirhead-Robinson Mercury-steel Coherer. *a*, steel disc rotated by clockwork; *d*, mercury cup; *c*, mercury covered with oil; *e*, contact springs; *f*, wiper for cleaning edge of disc.

transmitter are as shown in the left-hand diagram in Fig. 25, taken from their British specification, No. 11,348 of June 3, 1901.

The length of the aerial or the inductance in the closed circuit has to be so adjusted that the aerial is in resonance with the closed circuit. This takes place when the aerial has such a length that its free time period of oscillation is that of the closed circuit, or is equal to an harmonic of the latter.[30]

The receiving circuit similarly consisted of an aerial, *f*, attached to some point on a closed oscillation circuit consisting of a condenser, *o*, and variable inductance, *m*, some other point on this last circuit being connected to the earth through a condenser, *n*. The coherer *h* is connected in series with the condenser and inductance in the closed circuit, as shown in the right-hand diagram in Fig. 25, taken from



Transmitter. *Receiver.*

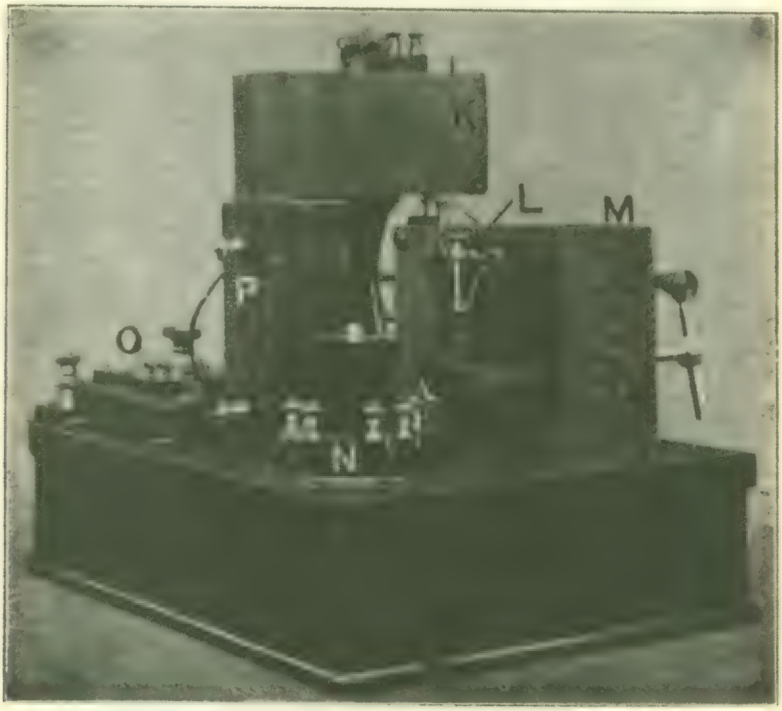
FIG. 25.—Diagram of Connections of Lodge-Muirhead Wireless Telegraph Transmitter and Receiver Apparatus.

the same British specification of Lodge and Muirhead, No. 13,521 of 1901.

The telegraphic recording instrument is a siphon recorder, and the local battery is a shunted cell which supplies an electromotive force of a fraction of a volt for working through the coherer. When the electromagnetic waves impinge on the aerial they set up oscillations which excite syntonic oscillations in the closed circuit associated with it, and these oscillations finally break down the insulation of the film of oil lying between the steel wheel and the mercury aided by the voltage of the local shunted cell. The siphon recorder in series with that cell then deflects and records a signal. If the train of arriving waves is short, then the record on the tape of the syphon recorder is a brief mark or triangular notch, corresponding to a *dot* on the Morse system. If the train of waves is more prolonged, then the mark on the tape is a square-shouldered notch, corresponding to a *dash* on the Morse code. In this manner the movement of the

[30] For a fuller discussion of the conditions of this resonance and the theory of such coupled circuits, see Chap. VIII. § 9 and § 10, of this treatise.

siphon recorder coil and associated pen imitates that of the key in the sending circuit. The siphon recorder, coherer, working cell, and shunt, or potentiometer, are combined in one piece of apparatus, as shown in Fig. 26. Instead of using a hand-manipulated Morse key at the sending end to create short or long trains of oscillatory sparks, and therefore waves, Dr. Muirhead employs an automatic sender, actuated by a perforated tape, as in the case of transmission by cable. The tape is perforated with the message in the usual manner by a hand-worked perforator, which punches the paper tape, as for the Wheatstone automatic transmitter, with the Morse symbols for each letter. The tape is then sent through a transmitter, which closes the circuit of a vibrating break or buzzer in the primary



From "The Electrician."

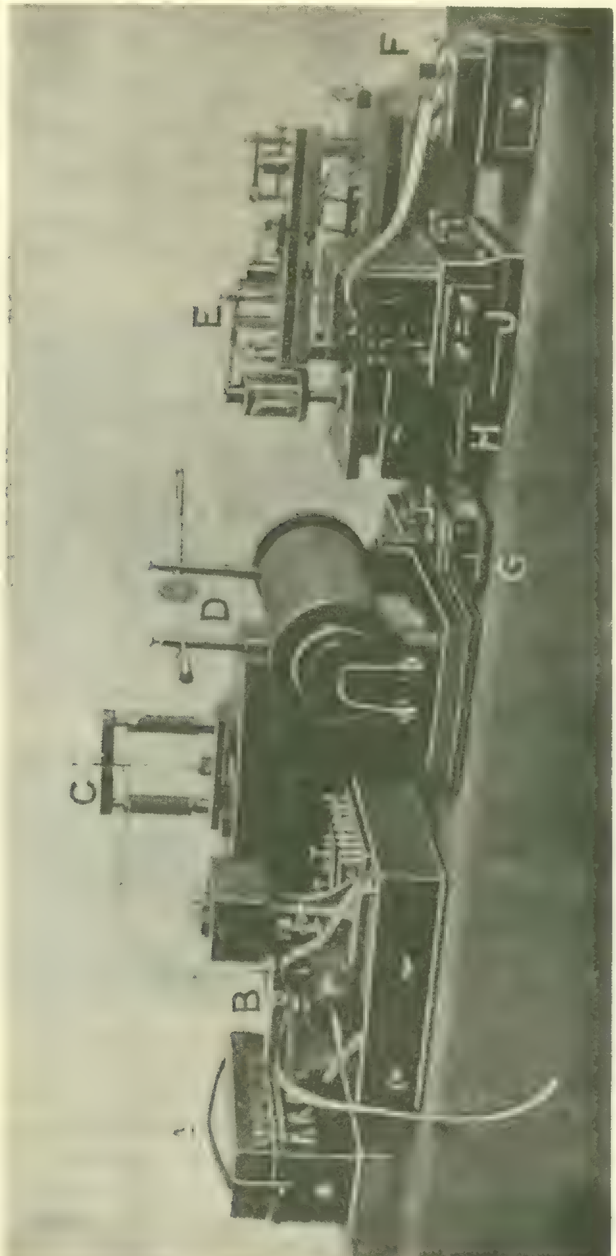
FIG. 26.—Lodge-Muirhead Combined Siphon Recorder, Coherer, Potentiometer, and Working Cell for their Wireless Telegraph Receiver.

circuit of the induction coil for a time, corresponding to the dash or dot on the Morse system. A view of the collected apparatus is shown in Figs. 27 and 27A.

The rotating steel disc cymoscope is said to work with great ease, regularity, and speed, and the advantages of dispensing with any form of sensitive relay are considerable. At the same time there is the advantage of a printed record of the message.

12. Work of Slaby and Von Arco on Wireless Telegraphy.—Dr. Adolf Slaby, one of the engineering professors in the Technical High School at Charlottenburg, Berlin, had his attention drawn to the utilization of Hertzian waves for telegraphic purposes prior to the date when Marconi's work became known, but, according to his

own statements, he obtained no practical results until the clue to success was given to him by witnessing, early in 1897, Marconi's



From "Page's Weekly Magazine."

Fig. 27.—Lodge-Muirhead Apparatus for Electric Wave Wireless Telegraphy. A, 12-volt battery; B, combined siphon recorder and coherer; C, spark discharger; D, induction coil; E, buzzer or coil interrupter; F, tape perforator; G, Morse key; H, primary switch; J, autotransmitter.

demonstrations across the Bristol Channel.[31] From that time he has been a diligent worker in this field of research.

At the very outset he carefully studied the distribution of electric

[31] See an article on "The New Telegraphy," by Dr. A. Slaby, *The Century Magazine*, April, 1898, vol. 55, p. 870.

potential and current in the aerial wire as used originally by Marconi, and saw that stationary electric waves were set up in it, so that when vibrating electrically in the fundamental mode there was a node of potential at the base of the Marconi aerial and an antinode at the summit. This he saw applied not only to the transmitting aerial

From "Page's Weekly Magazine."

FIG. 27A.—Another View of the Signalling Key, Autotransmitter, and Perforator of Lodge-Muirhead Wireless Telegraphic Apparatus.

but to the receiving aerial. It then became clear, from the study he made of the Branly metallic filings tube, that this instrument depended for its operation on the application of a sudden and sufficient oscillatory electromotive force or potential difference between the ends of the tube. Hence the insertion of the tube

between the base of the aerial and the earth, as in the original Marconi arrangement, was using it under the least advantageous conditions.

Properly speaking, the tube should be inserted between the upper end of the aerial and the earth, so as to receive the maximum potential difference between its ends. This, however, is impossible without carrying up a second wire from the earth, which would then at once have a distribution of potential set up in it, similar to that in the aerial itself, and hence no difference of potential would exist between the ends of a coherer situated between the summits of the two equally tall aerials. Slaby, however, overcame the difficulty in a very ingenious manner. If we set up a vertical wire, AB (see Fig. 28), with its base connected to the earth in a region traversed by electric waves,

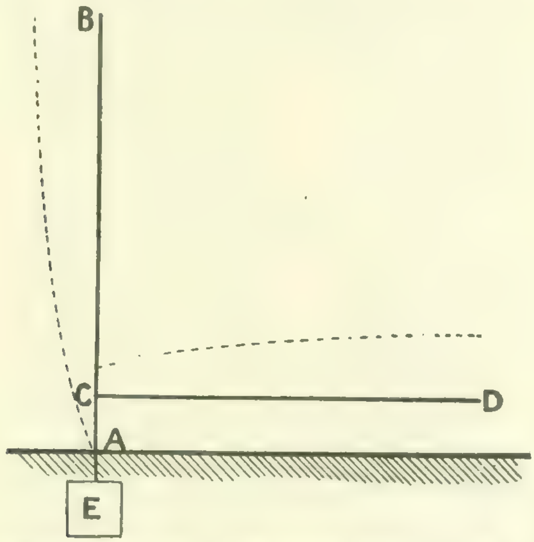


FIG. 28.—Slaby-Arco Antenna, AB, and Attached Syntonic Side Wire, CD. The distances of the dotted lines in the diagrams from the firm lines representing the antennæ denote the amplitude of the potential oscillations at the corresponding points.

we shall have stationary oscillations set up in it, when its length is adjusted to resonance with the time period of the impinging waves. If then we attach to a point two or three metres above the ground a horizontal wire, CD, of nearly equal length to the upper segment of the aerial (see Fig. 28), we shall have stationary oscillations of potential set up in both vertical and horizontal branches, as indicated by the ordinates of the dotted lines in Fig. 28. Hence there is a loop of potential at the outer end of the lateral wire as well as at the top of the vertical wire. We have easy access to the former point, and hence we can insert a coherer, F, between the outer end of the lateral wire and the earth E_1, placing in series with it a condenser, K, and shunting the condenser by a telegraphic relay, R, and local cell, G. The arrangement is shown in the diagram in Fig. 29, taken from the German patent, No. 130,723, of Slaby and Arco, applied for October 16, 1900. The claim made for the arrangement is that it enables

any vertical, earthed, but otherwise insulated, rod, such as a lightning conductor, to be employed as the aerial.

In a supplementary German patent, No. 131,585, applied for

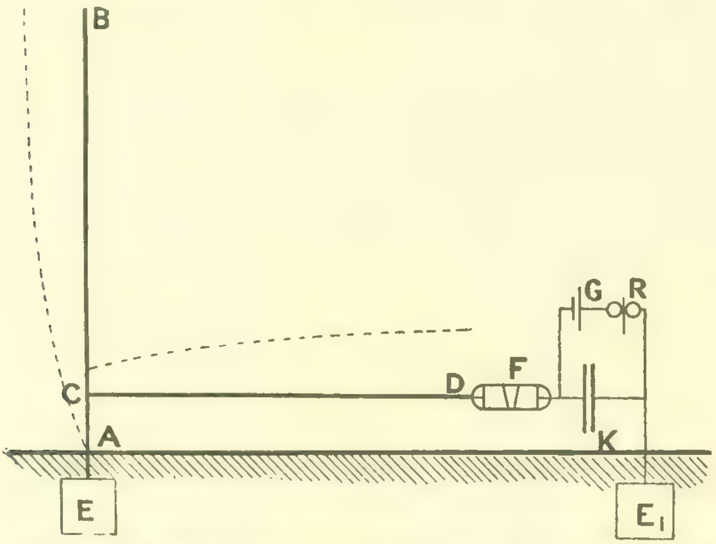


FIG. 29.—Slabo-Arco receiving antenna, AB; syntonic side wire, CD; coherer, F; condenser, K; relay, R; local cell, G; earth plates, E, E_1.

February 6, 1901, the horizontal wire is made to extend for a distance double the height of the vertical aerial, and the outer end of the horizontal wire is earthed at E_3, and the coherer inserted between an earth, E_2, and a half way point, B, on the horizontal wire (see Fig. 30).

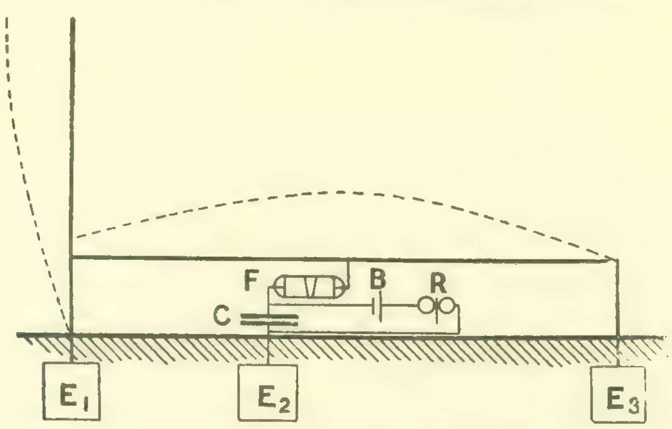


FIG. 30.—Another Slaby-Arco Arrangement of Receiving Apparatus with syntonic side wire of double length. Coherer, F; condenser, C; relay, R; working cell, B; earth plates, E_1, E_2, E_3.

In these diagrams the dotted lines represent by their distance from the aerial wires (firm lines) the amplitude of the potential oscillation at each point in the wire, and show, therefore, the position of the nodes and loops of potential.

The corresponding transmitter is described in the German patent, No. 131,586, applied for November 9, 1900, and consists of a vertical aerial, AB, and a pair of spark balls, S, interposed between a horizontal extension wire, CD, and the vertical antenna. The secondary terminals of the induction coil I are connected to the spark balls (see Fig. 31).

The operation of the receiving aerial is as follows:—

Referring to the diagram in Fig. 29, E represents the earth plate and AB the vertical aerial. The lateral wire CD is equal in length to the section CB of the vertical aerial, and F is the coherer tube placed at D, and a condenser, K, earthed at one side, is in series with it. The condenser is shunted by a single local cell, G, and a relay or recorder, R. When oscillations take place in the aerial, the point D in the lateral wire is an antinode of potential. Hence the coherer gets the benefit of the maximum potential oscillations, and as soon as it becomes conductive the cell G sends a current through the relay R and coherer F, and down through the aerial earth plate E, and up again through the condenser earth plate E_1, so completing the circuit.

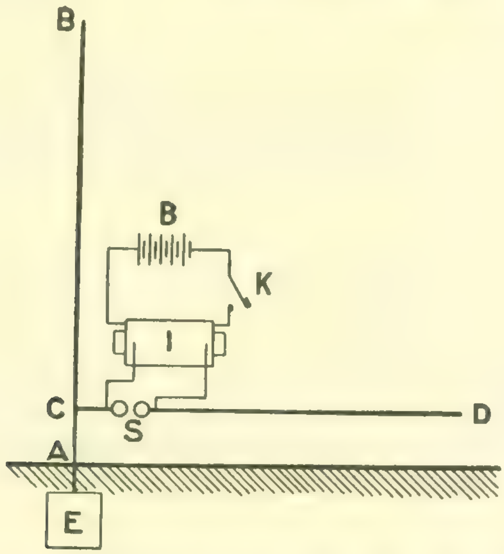


Fig. 31. Slaby-Arco transmitting antenna, CB; side wire, CD; spark balls, S; induction coil, I; earth plate, E; battery, B; key, K.

It is not necessary that the lateral wire CD should be laid out straight. It may be coiled in an open spiral (see Fig. 32), and somewhat shortened to compensate for increased inductance. In this form the open spiral CD becomes a means of exalting the potential oscillations at the point D, so that the amplitude is greater at D than at C. Professor Slaby, therefore, called a coil so adjusted a *multiplier*.

Associated with this receiving arrangement, we have the transmitting system, as shown in Fig. 31, where AB is the transmitting aerial, and S the spark balls, and CD the horizontal wire, which in the same manner need not be stretched out straight, but may be loosely coiled

into a spiral. The spark balls are connected to the secondary terminals of an induction coil, and oscillations are set up in the horizontal and vertical wires with an antinode of potential at the open ends.

The above arrangements, therefore, are well adapted for utilizing as aerials any two vertical wires or rods earthed at the lower end but insulated elsewhere, such as two lightning rods. Moreover, Slaby saw that it would be possible to adapt these arrangements to syntonic telegraphy. Let two transmitter aerials, AB and A′B′, be set up, one having an upper section 1·5 times the length of the other, each being provided with appropriate coiled side wires and interposed spark balls (see Fig. 33). Then let one receiving aerial, *ab*, be established at a distance having a height equal to AB. To this let two lateral wires be adapted, one of them, *bd*, of such a length that $bd = ab = AB$, and

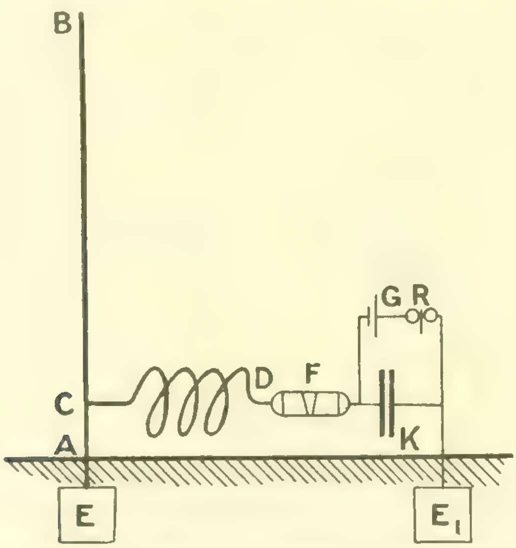


FIG. 32.—Alternative Slaby-Arco Receiving Arrangement, with side wire, CD, coiled into an open spiral.

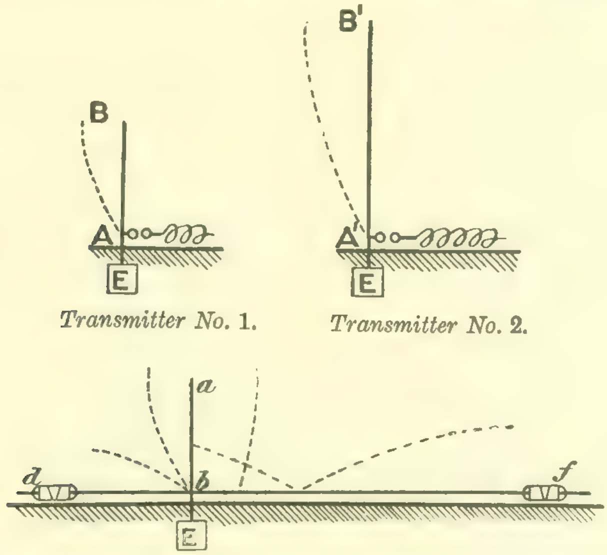
the other, *bf*, of such a length that $ab + bf = 2A'B'$. If then the fundamental oscillation of the aerial AB is excited, its radiation will set up oscillations in the section $ab + bd$ of the receiving aerial. If, however, the fundamental oscillations of the aerial A′B′ are excited, their radiation will cause the section $ab + bf$ to be excited. Accordingly, if coherers are put at the outer ends *d* and *f*, and earthed through condensers, which are also shunted by local cells and relays, we shall have a system of two transmitter rods and one receiving, which enables duplex simultaneous or syntonic telegraphy to be conducted.[32]

Professor Slaby made an exhibition of this method in a lecture given in Berlin on December 22, 1900, in the conference room of the General Electric Company of Berlin, in the presence of H.M. the Emperor of Germany. The lecture was entitled, "Syntonic and

[32] See German Patent, No. 131,584, granted to the General Electrical Company of Berlin, application of November 9, 1900.

"Multiple Spark Telegraphy." [33] In this demonstration simultaneous telegraphy was conducted between a transmitting station at the Technical High School at Charlottenburg, at Berlin, and the works of the General Electric Company, 2·5 miles, or 4 kilometres, distance, and also between the latter place and a cable manufactory at Oberschöneweide, 9·3 miles, or 14 kilometres, distance. The two wave lengths used were respectively 640 metres and 240 metres. Good independent simultaneous telegraphy was conducted.

Other variations of the horizontal wire arrangement of aerial devised by the same patentees are as follows: In the German patent, No. 127,730, of November 10, 1900, a lateral coiled wire is attached to a vertical aerial at a point a little way above the ground. This lateral coil has such a length that there is a node of potential at the



Transmitter No. 1. *Transmitter No. 2.*

Double receiving antenna.

FIG. 33.—Slaby-Arco Arrangements for Duplex Syntonic Telegraphy. The dotted lines in the diagrams denote the amplitude of the potential oscillations in the antennæ at the corresponding points.

centre and an antinode of potential at its outer end. Hence if a coherer in series with a condenser is joined between the base of the aerial and the outer end of the lateral wire, it will be acted upon by the maximum difference of potential. The condenser is shunted as usual by a relay and local cell.

In a pendant patent, No. 130,122, of December 13, 1900, the condenser shunted by the relay and cell is transferred to the centre of the lateral wire, where there is a node of potential, as in that case it produces a less disturbance of the potential distribution.

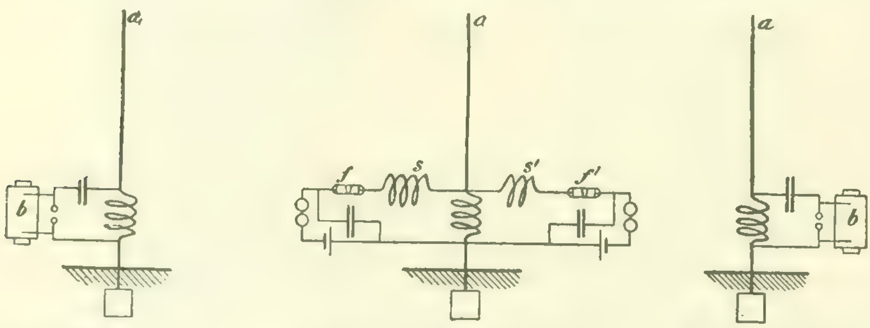
It will be seen on examining the arrangements of the above-described syntonic system of Slaby and Arco, that if we substitute one single earth plate for the two earth plates used in Fig. 32, the

[33] "Abgestimmte und Mehrfache Funkentelegraphie," by A. Slaby, see *Elektrotechnische Zeitschrift*, 1901, or *The Electrician*, January 18, 1901, vol. 46, p. 475.

oscillating circuits at the sending and receiving end each resolve themselves into a closed oscillating circuit containing a capacity, inductance, and either spark gap or coherer arranged in series, this oscillating circuit having one point connected to earth and the other to an aerial wire or open oscillating circuit which is in resonance with the closed circuit. Hence we arrive at the arrangement which is now generally called the direct-coupled aerial system. The practical arrangement of the Slaby-Arco system of multiple or syntonic telegraphy was, therefore, modified later on into the form shown in Fig. 34.

Each transmitter consists of a condenser suitable for working with high potentials, and this is connected in series with a variable inductance and the two joined to the spark balls of the secondary circuit of an induction coil. One end of this inductance coil is joined to an earth plate and the other end to an aerial wire.

The receiving circuit is very similar. In it we have an aerial wire connected to earth through an inductance coil, and to the terminals of this last-named coil are connected one, two, or three oscillatory circuits,



Transmitter No. 1. *Double receiving station.* *Transmitter No. 2.*

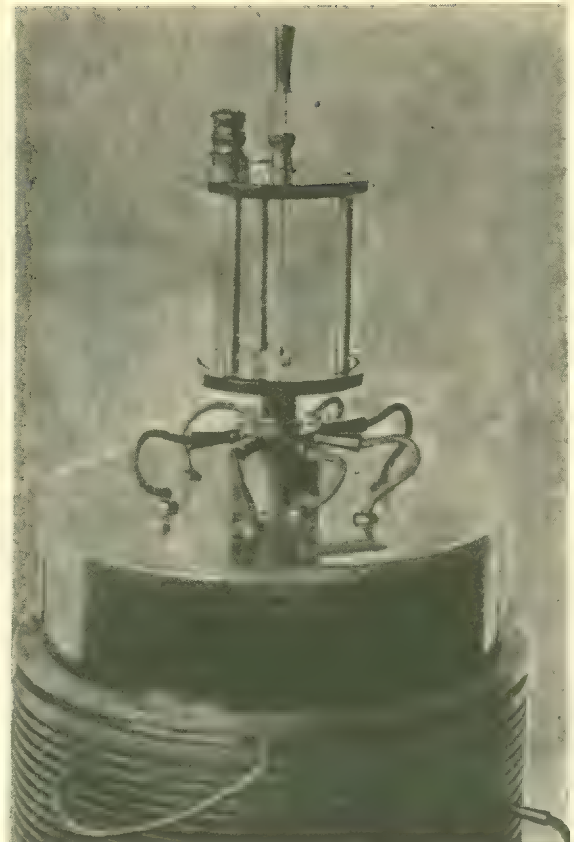
FIG. 34.—Scheme of Circuits of Slaby-Arco Apparatus for Duplex Syntonic Electric Wave Telegraphy, omitting Tuning Coils.

each of which consists of a variable inductance coil for syntonizing s or s', a coherer, f or f', and a condenser. A relay and local cell is connected across the terminals of each condenser.

The condenser in the transmitter circuit consists of a battery of five or six Leyden jars contained in an insulating vessel (see Fig. 35). The total capacity may be about 0·001 mfd. On the top of this is placed the adjustable spark gap, and round the vessel containing the Leyden jars is coiled the variable inductance coil, consisting of bare copper wire wound in a groove in an ebonite cylinder (see Figs. 36 and 37). The upper or adjustable spark ball is the earthed ball, and the spark gap condensers and inductance are joined in series. The aerial is connected to the end of the inductance furthest from the earthed spark ball. This oscillation circuit is excited by an induction coil giving a 25 cm. spark, and the primary current is interrupted by a mercury turbine break suspended in gimbals (see Fig. 38). On board ship the induction coil is fixed up against a bulkhead and the break suspended underneath the operating table. The appearance of the complete set is shown in Fig. 39 (see p. 574).

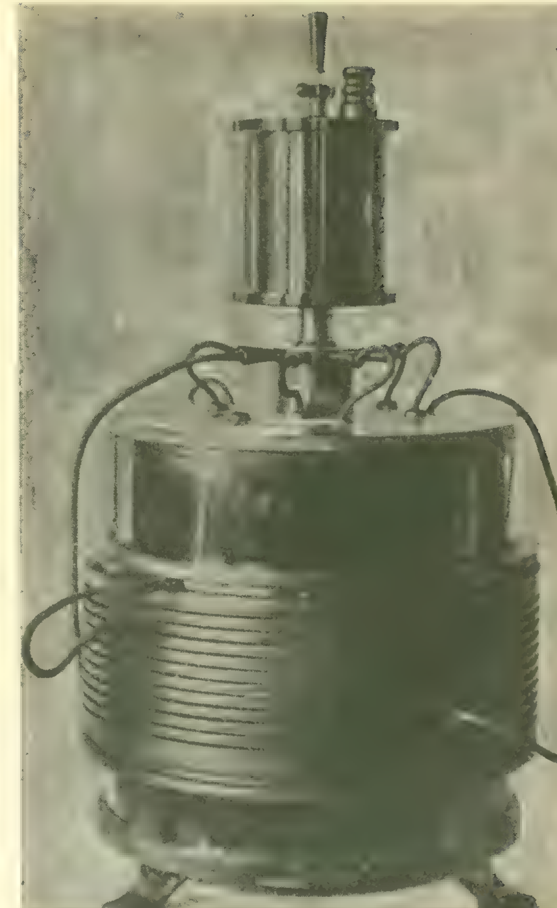
From "Traction and Transmission."

FIG. 35.—Battery of Leyden Jars forming the Condenser in Slaby-Arco Transmitter.



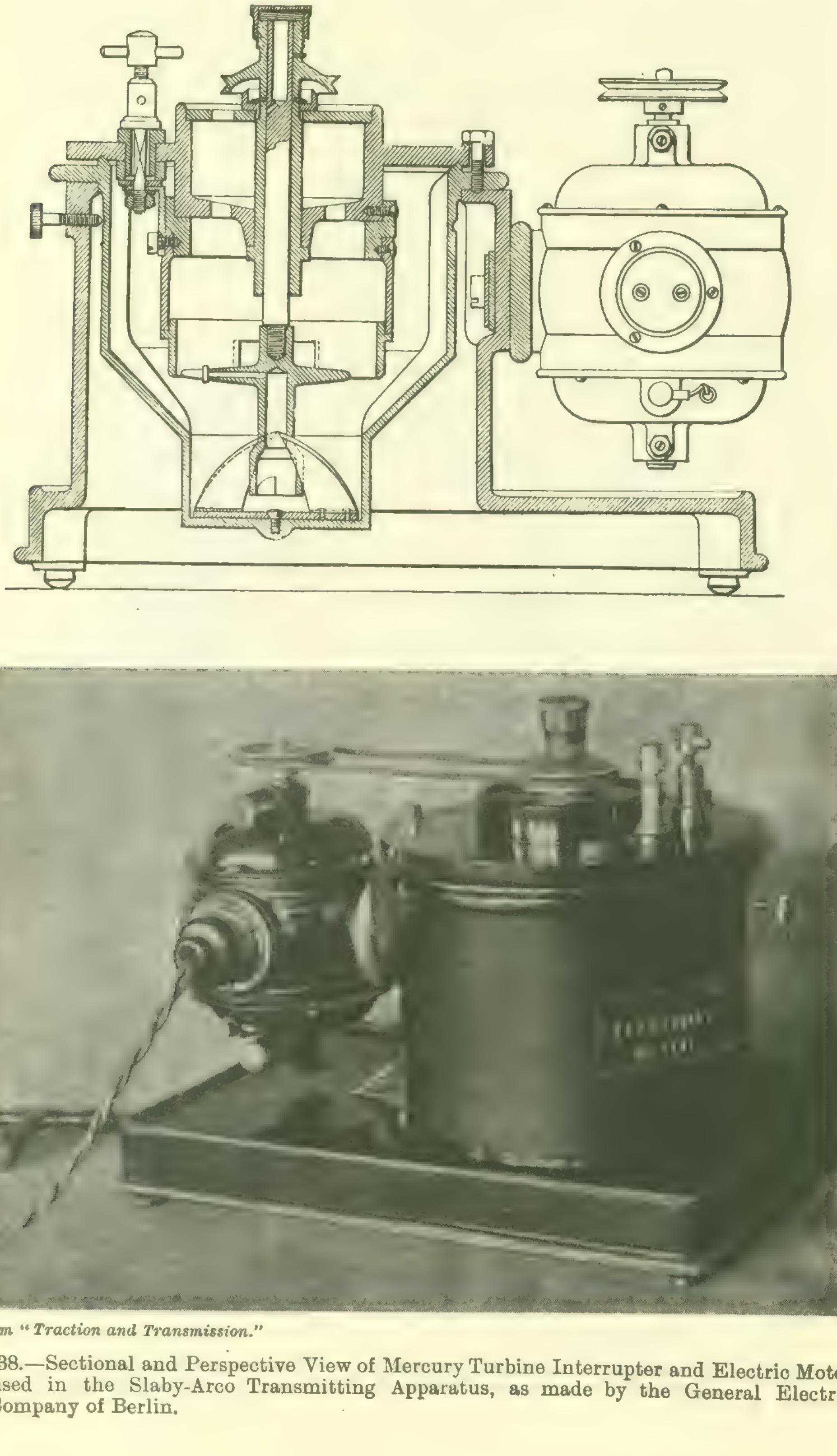
From "Traction and Transmission."

FIG. 36.—Adjustable Spark Discharger and Variable Inductance in Slaby-Arco Transmitter.



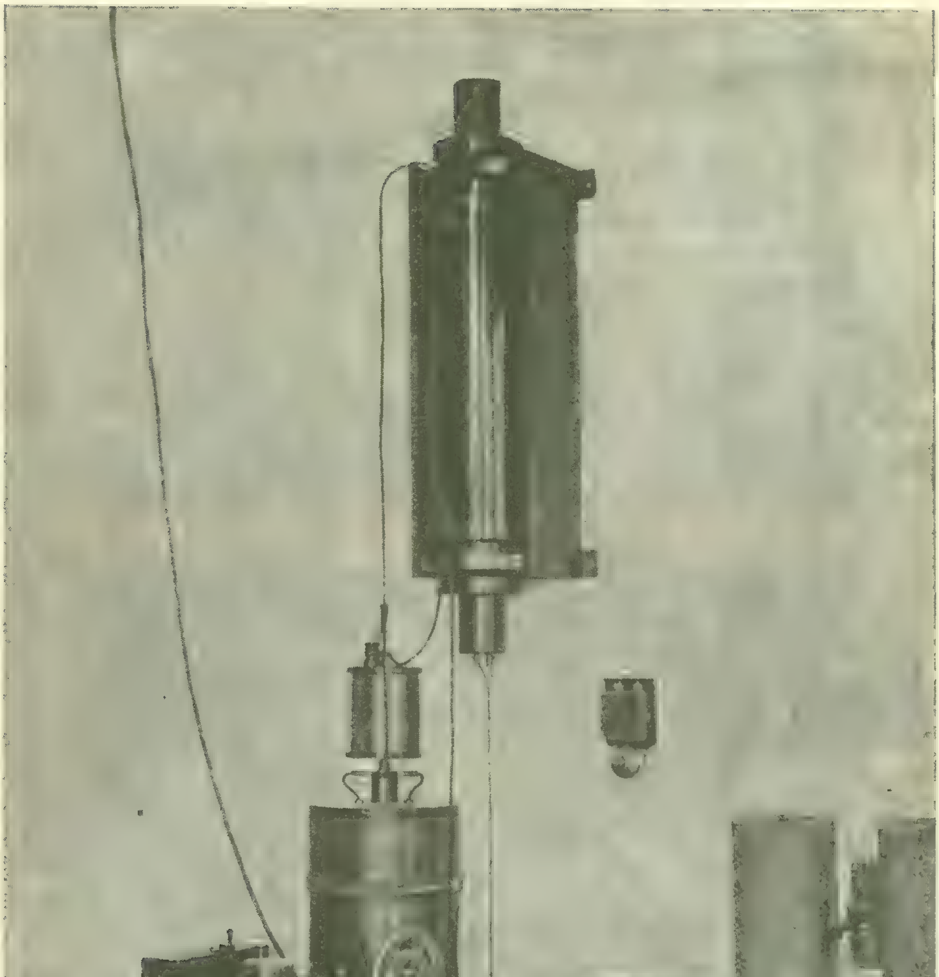
From "Traction and Transmission."

FIG. 37.—Discharger and Inductance Coil Enclosing Leyden Jars in Slaby-Arco Transmitter.



From "Traction and Transmission."

FIG. 38.—Sectional and Perspective View of Mercury Turbine Interrupter and Electric Motor used in the Slaby-Arco Transmitting Apparatus, as made by the General Electric Company of Berlin.



From "Traction and Transmission."

FIG. 39.—View of Complete Slaby-Arco Apparatus for Electric Wave Telegraphy, showing the Induction Coil fastened to the Wall and the Turbine Mercury Interrupter under the Table.

The coherer tube used resembles that of Marconi. It consists of a glass tube (see Fig. 40) exhausted of its air and containing two well-fitting bevelled silver plugs with ends in close apposition. Between them is a small quantity of nickel filings. The coherer is held in a clip so that it can be turned round to make the filings lie in a wider or narrower portion of the gap, and so vary the sensibility. The coherer is tapped by an automatic electromagnetic hammer.

The primary circuit of the induction coil contains a Morse key for signalling, with magnetic blow-out to stop sparkling, and the receiving circuit contains a relay and Morse inker.

In order to adjust the transmitter and receiver to syntonism, Count Arco devised a portable syntonizing coil, which allows any number of stations to be brought to the same "tune" or period. The arrangement is shown diagrammatically and objectively in Fig. 41.

It consists of a variable inductance coil and condenser, the condenser having a pair of adjustable spark balls connected to its terminals. When one transmitting station has been brought to resonance with any receiving station, the syntonizing coil is applied, as shown in the lower diagram (Fig. 41), to the base of the transmitting aerial *a*, and the inductance A of the syntonizer adjusted until the longest spark is obtained at the spark points *h*. The syntonizer is then removed to some other transmitter station, and the variable inductance

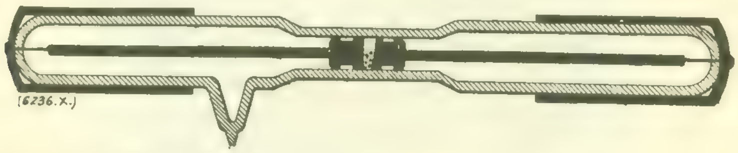
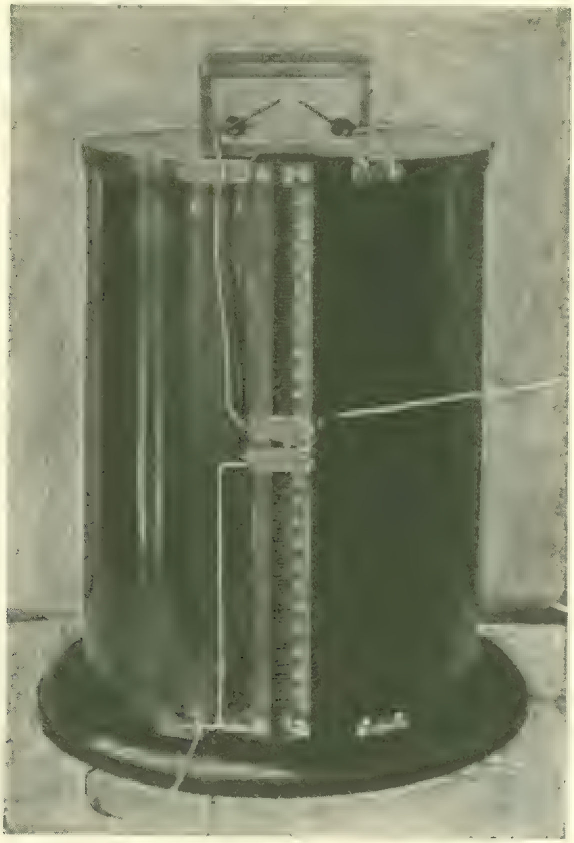

(6236.X.)

Fig. 40.—Metallic Filings Cymoscope used in Slaby-Arco Receiver.

of the transmitter is altered until the syntonizer gives a spark equally long when attached as shown in the diagram. This appliance is, however, only a rather rough form of cymometer, and better results can be obtained by measuring the wave lengths of the wave emitted by the transmitter and adjusting the inductance coil of the latter until the required wave length is obtained (see Chap. IX. § 4).

If the arrangement of Lodge and Muirhead, as described in their British specification, No. 11,348 of 1901 (see p. 562), is compared with that of Slaby and Arco just described as developed by the General Electric Company of Berlin, it will be seen that there is no essential difference between them. In each case we have a closed oscillatory circuit connected at one point to the earth and at another to an aerial. We may, in fact, say that no one has yet devised any form of transmitter and receiver for electric wave telegraphy which does not fall under one of the three following forms (see Fig. 41). First, the transmitter is either a simple insulated aerial wire with spark ball at the lower end, and a corresponding spark ball connected to an earth plate. This is the original arrangement of Marconi, and is now called the *plain aerial*. In the next place, the oscillations may be set up in a closed oscillatory circuit which is connected at one point to the earth and has an aerial wire in syntony with it connected to some other point. This is called the *direct-coupled aerial*, and is

the typical form of the arrangements of Lodge, Muirhead, and Slaby-Arco systems. In the third place, the aerial may be connected



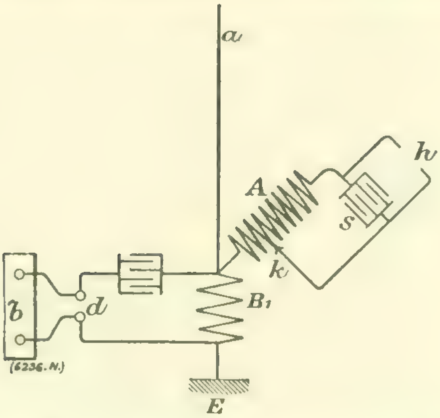


FIG. 41.—Arco Syntonizer for adjusting Time Periods of Antennæ. *a*, antenna; A, inductance coil; S, condenser; *h*, spark points; *k*, sliding contact.

inductively or through an oscillation transformer with the aerial. This is the method employed by Marconi, and, as we shall see in the next section, also by Braun. There is no essential difference between

the so-called direct-coupled and inductively-coupled methods. In the one case an autotransformer or single coil transformer connects the antenna to the energizing circuit. In the other case a two-coil transformer is employed.

In addition to the arrangements above described, Slaby and Arco devised also forms of closed loop receiver and transmitter aerial, to which reference has already been made (see Chap. IV. § 8).

If a closed oscillatory circuit is formed consisting of a condenser, loop of wire, and spark gap, we may set up oscillations in it by connecting the spark balls to an induction coil. We have in this case, however, no radiation if the length of the loop, compared with its fundamental wave length, is such that the current is at all points in the same direction at the same instant.

Slaby and Arco found that if the loop is constructed with unequal inductance on its two sides, and connected to the earth at one point, then harmonic oscillations can be set up in it such that there is a node of potential at the earthed end and an antinode or loop at the upper end. In this case the loop acts as if it were two simple Marconi aerials connected together at the top. The arrangements adopted in practice for the transmitter loop, as shown in the German patent specification of Slaby and Arco, No. 133,718, applied for November 4, 1899, are as follows:—

A condenser has one terminal connected to earth and the other to the lower spark ball of a discharger. The upper spark ball is connected to an aerial composed of a group of parallel wires, and the upper end of this aerial is connected to earth through an inductance coil or wire with considerable inductance.

One way in which we may view the operation of this loop antenna is to consider that the inductance connected between the upper end of the aerial and the earth, whilst not offering impedance enough to prevent the relatively slow charging of the aerial and condenser, acts like a perfect insulation toward the high frequency oscillations set up at each discharge.

Another of these looped aerials is described by Slaby and Arco in their German patent, No. 124,154, dated December 23, 1898. In one form the transmitting loop consists of a vertical rectangular loop of wire having a condenser in one side and a pair of spark balls below it, the loop being earthed at the bottom. If the fundamental oscillation is set up in the loop it does not radiate, for the reasons explained in Chap. IV. § 8 of this treatise. If, however, a harmonic oscillation is set up so that the upper end of the loop is an antinode of potential and the lower end a node, radiation is emitted from it. Corresponding to this looped transmitter the patentees described in the same specification a looped receiving aerial in which the coherer and working cell and relay are placed in one side of the loop, and, if need be, a condenser arranged in parallel with the other side. The lower end of the loop is earthed. The patentees say that it has been shown by experiment that such a transmitting loop produces different effects in different directions, and for the best effect it is necessary to erect the transmitting and receiving loops so that their planes are parallel and at right angles to the line joining their centres.

The General Electric Company of Berlin also described at a later

date, in a German patent, No. 129,892, dated October 16, 1900, a looped receiving aerial. If two simple straight aerials are set up side by side, and acted upon by incident electromagnetic waves of suitable period, they would exhibit no difference of potential between points at equal height from the ground, and a coherer joined in between these points would not be affected. If one of the aerials is lengthened at the bottom by a loop equal in length to its own height, and if the two aerials are connected together at the top and earthed at one point (see Fig. 42), the coherer, joined across as shown, will be affected strongly. We may cause a telegraphic printing instrument to record as usual by inserting a condenser shunted by a relay and local cell in series with the coherer, and operating the printer by the relay. The inventors say that the earthing in this case is not necessary;

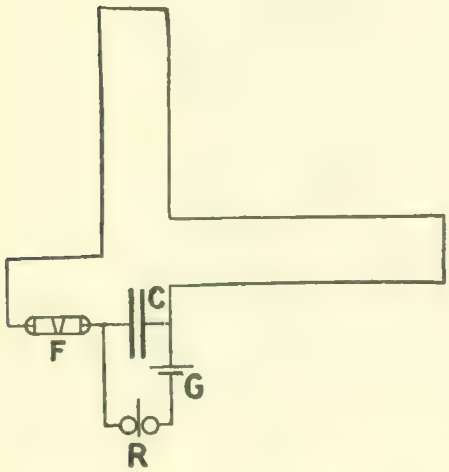


Fig. 42.—Closed Circuit Receiving Antenna of the General Electric Company, Berlin. F, coherer; C, condenser; R, relay; G, cell.

Fig. 43.—Parallel Antennæ, one having inductance, L, in series with it.

also that by the use of the loop circuit disturbances due to atmospheric electricity are avoided. They also gave a diagram in which two aerials not connected at the top act as plates of a condenser to each other. In one aerial wire an inductance coil is inserted (see Fig. 43), and a coherer shunted by a working cell, and a relay is connected across between the two aerials at the bottom.

Slaby and Arco, or their patent assignees, the General Electric Company of Berlin, applied for several German patents describing variations or combinations of the above forms of aerials.

In some cases they made use of the exalted potential, generated at the extremity of a resonant coil, to charge another aerial of the straight or looped form.

Thus the arrangement of transmitter described in the German patent, No. 126,273, of February 28, 1901, is interesting. Oscillations

are set up in a closed circuit containing a condenser, C, and inductance, L, and to one point on this circuit the end of a resonant or multiplier coil, M, is attached, and the exalted potential at the other end of this last coil is caused to charge a loop transmitting aerial, A (see Fig. 44).

Another form of this circuit was described by them previously in a German patent, class 21A, registered number 7775, applied for December 10, 1900. The action of these nearly closed circuit or loop antenna, whether used as radiators or receivers, was not clearly understood at this date (1900), and the reader is referred to Chap. VIII. § 3, for a fuller discussion of them.

A number of minor improvements by Slaby and Arco, some of

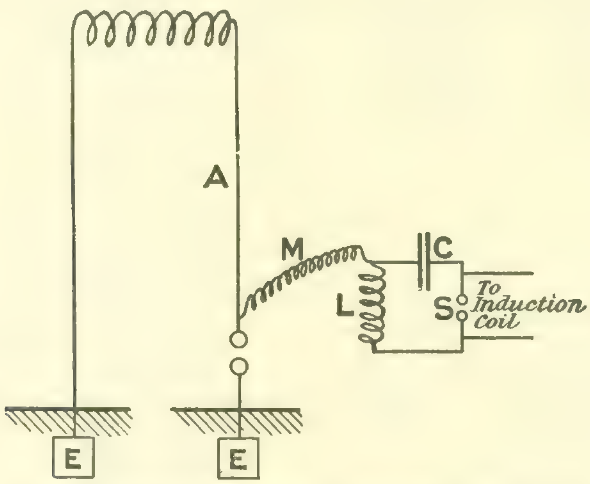


FIG. 44.—Loop Transmitting Antenna charged by means of a Tension Multiplying Coil, M, from a Closed Condenser Circuit, C, L, S.

which, however, were in use by Marconi previously, are described in other German patents, as follows:—

No. 113,285, of April 25, 1893.—This is an arrangement of the receiving apparatus for wireless telegraphy for the purpose of avoiding disturbances by the spark at the tapper, such that by an interruption of the local circuit through the coherer and that of the tapper magnet just before the hammer strikes the tube the spark at the armature contacts of the tapper magnet is over before the blow occurs, and thus at that instant no current is passing through the tube. Marconi, however, effects the required result quite satisfactorily by means of the choking coils he inserts in the connections leading from the coherer to the relay and local cell.

No. 116,071, of February 9, 1900.—In a receiving arrangement consisting of a coherer actuating a relay and Morse printer, the coherer is affixed to the armature of the Morse printer, instead of being tapped by a separate tapper. This arrangement, however, does not afford the required range of adjustment of the decohering blow.

No. 116,113, of March 24, 1900.—This is a patent for making the gap between the plugs in a coherer of the Marconi type wedge shape by bevelling the plugs so that by turning the tube round the sensibility of the tube can be altered within limits. This device has been patented many times by various inventors.

No. 129,017, of April 19, 1901.—This is a patent for a Morse signalling key for use in the primary circuit of an induction coil, provided with a permanent magnet to effect a magnetic blow-out of the spark.

13. Contributions of Professor F. Braun to Electromagnetic

Wave Telegraphy.—Professor Ferdinand Braun, of the University of Strasburg, has devoted considerable attention to the subject of wireless telegraphy by electromagnetic waves. His first German patent on the subject was applied for on October 14, 1898, No. 111,578.[34] He begins the specification by arbitrarily dividing electric oscillations into three groups—

(i.) Those created by mechanical means.

(ii.) Those produced by the discharge of Leyden jars.

(iii.) Those generated by Hertzian oscillations.

He states that the last variety alone have hitherto been utilized for wireless telegraphy. This division is, however, not founded upon any true scientific distinction between these various kinds of oscillations. The frequency of the oscillations, and therefore the length of wave sent out from a connected antenna, is merely a question of the capacity of the condenser or antenna used, and the inductance through which it is discharged, and a Hertz oscillator and Leyden jar are both special forms of condensers. Braun proposed in this specification, as a method of wave production, to include in the circuit of a Leyden jar, C, a spark gap, S, and an inductance coil, L, and, furthermore, to attach to one surface of the condenser an aerial wire, A, as a radiator (see I, Fig. 45). This arrangement is now called a direct-coupled aerial. Braun also proposes in the same specification to couple together the oscillatory circuit of the jar C and that of the aerial A inductively by means of an air core transformer (p, s) (see II, Fig. 45). This is now called the inductive coupling. The two diagrams in Fig. 45 are taken from Braun's specification. Braun, however, says nothing in the above-named specification as to the necessity for any relation between the natural time period of oscillation of his closed and open circuits.

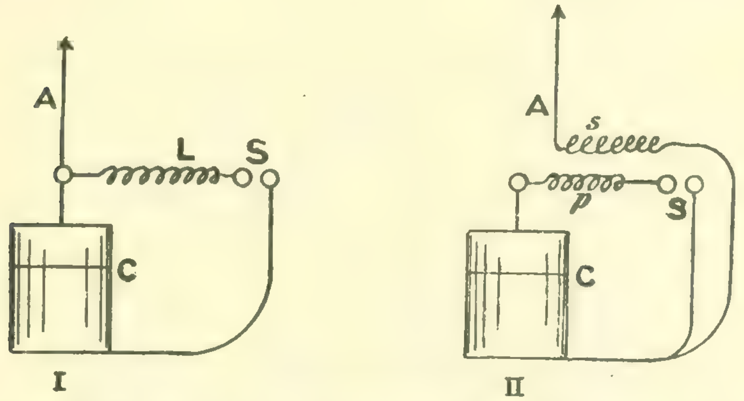


FIG. 45.—Diagrams taken from German Patent Specification, No. 111,578 of 1898, of Dr. F. Braun. C, Leyden jar; S, spark balls; A, antenna.

There is nothing in this first specification of Braun to show that he was aware of the reaction which the two circuits, open and closed, he couples together excite on each other, although it had been already mathematically discussed by A. Oberbeck (see Chap. III. § 11).

[34] The equivalent British patent specification is No. 1862, of January 26, 1899.

These circuits are, in fact, like two pendulums. Each has its own independent natural time period of oscillation when vibrating alone, and they may be coupled together in various ways. The mere haphazard coupling of two circuits, one a closed and the other an open or radiative circuit, does not necessarily result in the production of an oscillator which is, telegraphically speaking, more effective than the simple linear oscillator of Marconi.

Braun's suggested direct coupling of an aerial wire with a nearly closed oscillation circuit, consisting of a Leyden jar and associated inductance and spark balls, compared with the simple insulated conductor or aerial of Marconi, separated from the earth by a spark gap, does not produce a radiator having any special advantages unless there is a syntonism between the two coupled circuits. Neither is the inductive coupling of any special advantage unless the oscillation transformer is constructed in a particular manner. There is some indication in the opening remarks of Braun's specification, that he considered the real novelty in his invention to be the employment of the oscillations or discharges of a Leyden jar to create electric waves for telegraphic purposes, in place of the oscillations established directly of a simple linear or open circuit radiator containing a spark gap. It may be noted, however, that Lodge had previously in his British patent, No. 11,575, of 1897, proposed to employ the discharge of a Leyden jar to excite oscillations for radiotelegraphy. There are only two modes of coupling an open and closed oscillatory circuit which have any technical value. First, we may couple together the circuits in such a manner that a single pure oscillation or one single period of vibration is forced upon the aerial or radiator, not its own natural period, but that of the actuating closed circuit. Secondly, we may couple together circuits which have the same free natural time period when separate, and thus establish a syntonism between the circuits which, under the condition of a somewhat "loose coupling," results in the radiation of waves of two different wave lengths.

The first mode of operation was described by J. S. Stone (see § 20 of this chapter), and the second was discovered and worked out practically by Marconi. It has sometimes been suggested that Marconi availed himself of Braun's prior invention, but in truth his (Marconi's) investigations were carried on quite independently, and conducted to a more practical issue than those of Braun—at least up to the date when the latter secured his first German and equivalent British patent, No. 1862, of January 26, 1899.

Marconi provided at a little later date, in his British specification, No. 7777 of 1900, the definite information necessary for utilizing the inductive coupling, not simply as an isolated suggestion, but as part and parcel of a complete and practically operative system of syntonic electric wave telegraphy.

The mere fact that electrical oscillations produced by the discharge of a Leyden jar could be transformed in potential by an air core transformer, was already well known, and had been employed as far back as 1850 by Joseph Henry, and later by Tesla, Elihu Thomson, and others in 1890 and 1891. The mathematical theory of such oscillation transformers containing inductance and capacity in each circuit, commonly called Tesla coils, had been worked out some time

previously to the date of Braun's patent application by A. Oberbeck, M. Wien, and others.[35]

It was not even novel in 1898 to create induced electric oscillations in an open electric oscillatory circuit by inductively coupling it to another oscillatory circuit containing capacity inductance and a spark gap. In a lecture given in 1891, before the American Institute of Electrical Engineers, reported in a book entitled the "Inventions, Researches, and Writings of Nikola Tesla," published in New York in 1894, many diagrams and descriptions are given of oscillation transformers consisting of closed and open oscillatory circuits inductively coupled. On page 328 of the above-named book, in Fig. 175, is shown a diagram indicating an oscillation transformer of the Tesla type, the primary circuit consisting of a coil, through which the oscillatory discharge of a Leyden jar is sent, the secondary circuit consisting of a coil wound over the primary circuit, not closed, but furnished with extension wires, each ending in large plates, the whole secondary circuit thus forming an open oscillatory circuit of the Hertz type; many other diagrams are given in the same book which show that at that date (1894) Tesla was accustomed to employ an air core oscillation transformer to couple together inductively an open or radiative circuit and a closed oscillatory circuit through which the discharge of a Leyden jar was sent.

Lodge had also long previously shown that if a Leyden jar was provided with two discharge circuits, one called the A circuit and the other called the B circuit, then when an oscillatory discharge was set up in the A circuit it caused a sympathetic discharge in the B circuit, provided that there was a syntony between the time periods of the two circuits, so that one was equal to or a harmonic of the other. Lodge, however, did not propose to set in inductive connection two oscillatory circuits, one an open circuit or wire having capacity with reference to the earth, and the other a closed circuit having an equal or harmonically related time period.

It will be seen, however, that from the researches of Lodge, Slaby, Arco, and Braun has been developed the practical form of direct-coupled closed and open oscillatory circuits, which is a widely used type of transmitter in connection with wireless telegraphy. On the other hand, inductive coupling of an open and closed circuit, as described by Tesla and Braun, was brought by Marconi into a condition to be of real practical use in wireless telegraphy when he (Marconi) invented the proper form of oscillation transformer for coupling inductively his aerial radiator or vertical wire to a closed oscillation circuit of syntonic period.

There is, however, no fundamental difference between the forms of transmitter or receiver circuit in which a single coil or a double coil transformer respectively interconnect the antenna and the energy stirring condenser circuit. In both cases Marconi's method of syntonization of these circuits must be employed to obtain practical results.

The double-coil coupling offers certain advantages not possessed by the single-coil. We can inductively couple together the circuits

[35] See A. Oberbeck, *Wied. Ann.*, 1895, vol. 55, p. 623; also Geitler, *Wied. Ann.*, 1895, vol. 55, p. 513; and Max. Wien, *Wied. Ann.*, 1897, vol. 61, p. 151; also *Ann. der Physik* (4), 1902, vol. 8, p. 686.

"loosely" or "closely," and in general the inductive coupling gives us a facility for storing up larger amounts of electric energy to be released and imparted to the open circuit, and thence radiated as electric waves.

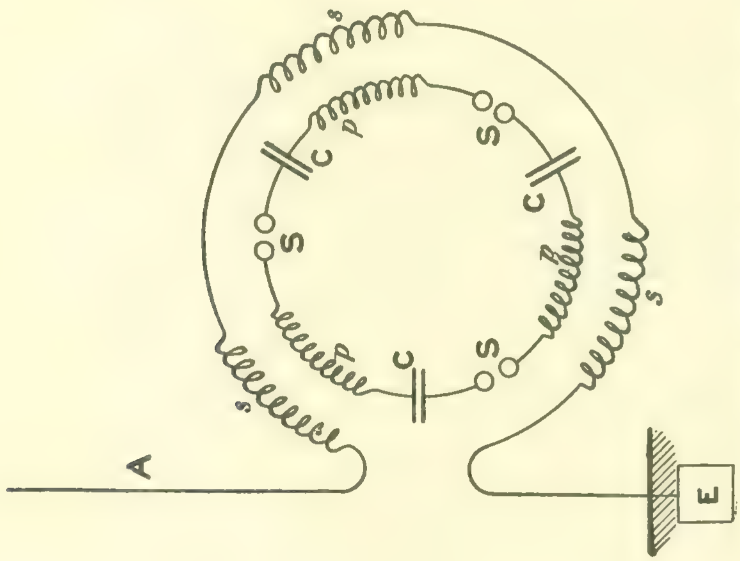


FIG. 48.—Inductive Coupling of Antenna and Condenser Circuits in Series. A, antenna; C, condensers; S, spark balls; p, s, oscillation transformers. (Braun.)

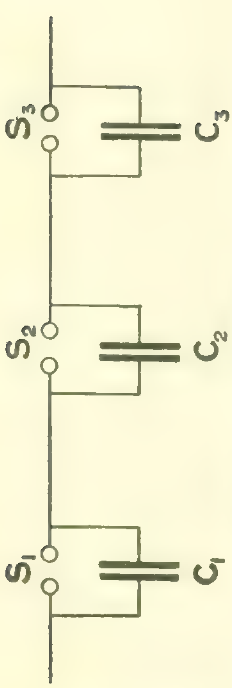


FIG. 46.—Arrangement of Condensers, C_1, C_2, C_3, and Spark Balls, S_1, S_2, S_3, in Series. (Braun.)

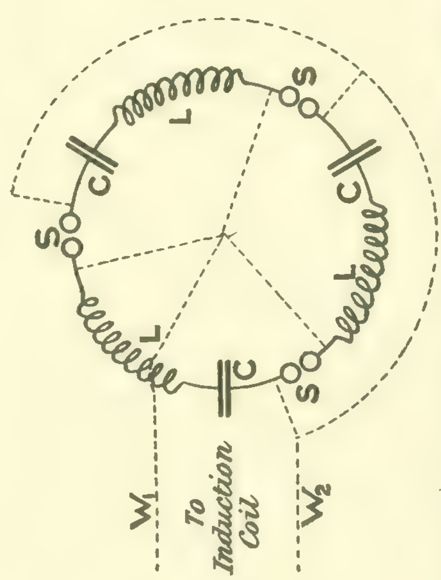


FIG. 47.—C, condensers; L, inductances; S, spark balls, arranged in series. (Braun.)

In a later German specification, No. 109,378, of January 26, 1899, Braun proposed to place Leyden jars, C_1, C_2, C_3, each with its own spark balls, S_1, S_2, S_3, these being joined in series for the sake of

accumulating voltage[36] (see Fig. 46). If we have n Leyden jars, each of capacity C, which will bear charging without damage to a potential V, we can arrange these jars either in parallel or series. In the first case we can charge the n jars each to a potential V, and accumulate a store of energy equal to $\frac{n}{2}CV^2$ in the n jars. In the next place we may charge the whole of the n jars in series to a potential nV, and accumulate a store of energy also equal to $\frac{1}{2}\cdot\frac{C}{n}(nV)^2$ or to $\frac{n}{2}CV^2$. The energy storage is the same in both cases, but the time period of oscillation is very different. Also there is a practical objection to the use of a long spark. We soon reach the limit at which the spark becomes non-oscillatory, and the damping by spark resistance very large. Braun, therefore, proposed to arrange the n jars

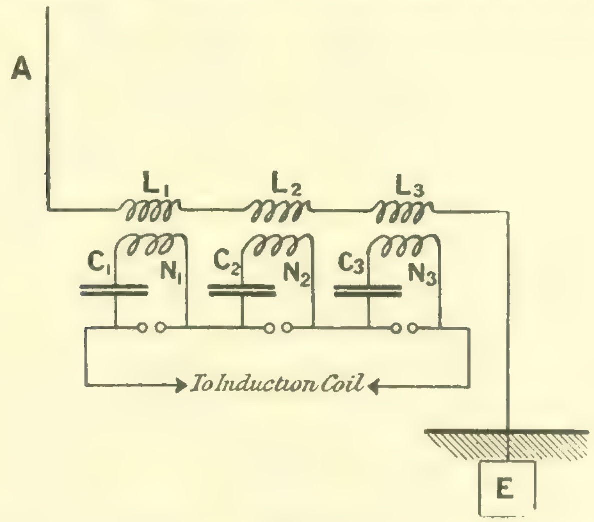


FIG. 49.—Arrangement of a Transmitter Circuit. (Braun.)

as in Fig 46, each with its own discharge circuit, so that whilst a total potential difference nV could be used in charging, and a total energy $\frac{n}{2}CV^2$ be stored up, equal to n times that in one jar, the time period of oscillation would not be changed, but each condenser would discharge through its own short spark gap. He proposed to employ the oscillations so created to generate inductively others in a secondary circuit, as shown in Fig. 49.

Another of Professor Braun's arrangements is shown in Fig. 47. In this a number of condensers, C, each having an associated inductance, L, are arranged in series with spark gaps, S, between. These condensers are all charged in parallel from two circuits, $- W_1$ and $+ W_2$, maintained in connection with the secondary terminals of an induction coil. When the potential between the spark balls rises to the breakdown point fixed by the length of the spark gap, the

[36] See F. Braun, British Specification, No. 5104, of March 8, 1899.

condensers discharge into one another with oscillations. The time period of one condenser and inductance alone would be equal to $2\pi\sqrt{CL}$. The time period of the n condensers and inductances in series is just the same, being equal to $2\pi\sqrt{\frac{C}{n}.nL}$. In the last case, however, the energy storage is n times that in a single condenser charged to the same potential. Braun associates this closed compound oscillatory circuit with an open radiative one, either directly coupled or inductively coupled.

In another arrangement (see Fig. 48) a number of condensers are charged in series, as in Fig. 48, and each discharges through its own inductive circuit and spark gap, the circuit being the primary coil p of an air core transformer. The secondary circuits s of all these transformers are joined in series with each other, and the series interposed between an aerial, A, and the earth, E. The object of this arrangement is to secure a high potential or electromotive force in the radiative circuit, and yet to keep the wave length moderately small, and, above all, the damping due to spark resistance small. An alternative arrangement is shown in Fig. 49. The inventor is thus able to secure energetic trains of slightly damped waves. The separate condenser circuits, each consisting of condenser, spark gap, and inductance, may be charged in parallel from a constant supply, and the secondary oscillations induced by these discharges added together, as regards electromotive force, by joining the secondary circuits in series with an aerial.

14. The Braun-Siemens Practical System.—In bringing his devices and improvements in wireless telegraphy into practical form, Professor F. Braun associated himself with the firm of Siemens and Halske, of Berlin, just as Professor Slaby and Count Von Arco placed their inventions in the hands of the Allgemeine Elektricitäts Gesellschaft (The General Electric Company), of Berlin.

Braun's methods finally took the following form. At the transmitting end an induction coil, I (see Fig. 50), had its secondary terminals connected to two spark balls, S, and these, again, were connected by two condensers, C, C_1, in series with the primary circuit p of an oscillation transformer, T. The secondary circuit s of this oscillation transformer was inserted in between the aerial A and a large cylinder, K, acting as a balancing capacity, which took the place of the earth.

In practical apparatus Braun employed as the primary condenser a collection of glass tubes partly coated on both sides with silver or tinfoil, so as to form tubular Leyden jars of small capacity, and more or less of these were associated in parallel as required (see Fig. 51) (see p. 587). The large capacity K to which the base of the aerial is connected consists of a metal cylinder (see Fig. 56). The sending oscillation transformer consisted of a primary circuit of very low resistance of very few turns, having a secondary circuit wound over it, the two being placed in an oil bath (see Fig. 52). The primary circuit of the charging induction coil contained a Wehnelt interrupter (see Figs. 53 and 54) and a Morse key with magnetic blow-out. At the receiving end an oscillation transformer had one circuit inserted in between the aerial wire and the large capacity representing the earth. The other circuit was connected through a condenser with a coherer.

This consisted in one form of a tube with polished steel adjusted plug electrodes containing between them steel powder. The sensibility was varied by a small ring magnet. Some form of tapping arrangement was employed to decohere the steel filings. The sensitive tube was shunted as usual with a relay and local cell, and the relay connected with a Morse printing instrument and local battery. The receiving arrangement thus contains all the essential elements of Marconi's system of wireless telegraphy, but modified by the use of an insulated capacity in place of the earth connections. In some cases a steel carbon microphone used in series with a single cell and telephone has been employed as a detector in connection with the Braun-Siemens

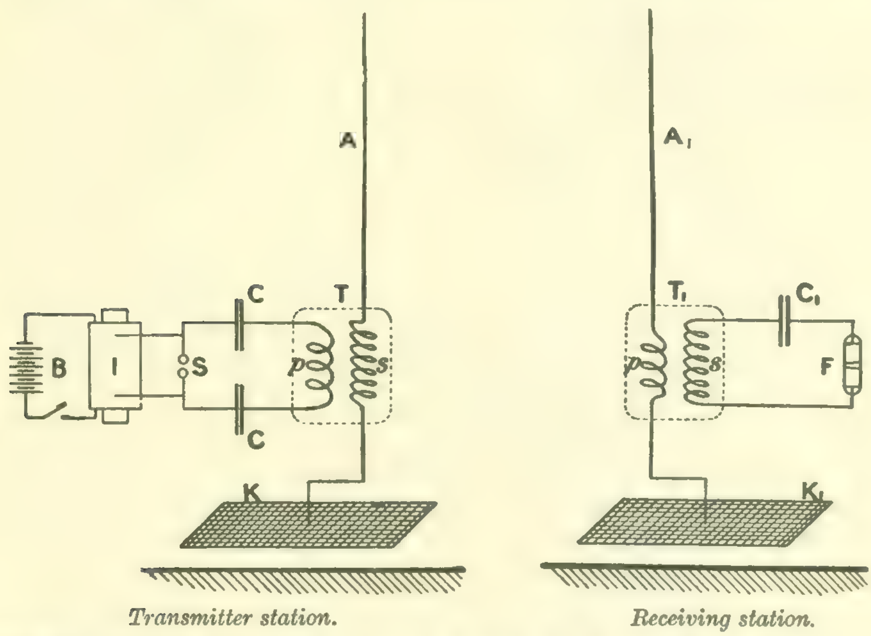


FIG. 50.—Inductively Coupled Antennæ as used for Electric Wave Telegraphy. I, induction coil; S, spark gap; C, C_1, condensers; T, T_1, oscillation transformers; A, A_1, antennæ; F, sensitive tube, or coherer; K, K_1, balancing capacities. The Tuning Coils in the Antenna Circuits are omitted.

stations. The whole arrangement of the station is shown in Fig. 55 (see p. 588).

Braun tried his methods in the summers of 1899 and 1900 between Cuxhaven and Heligoland, a distance of 63 kilometres (40 miles), using aerial wires 30 metres high, and maintained his transmitting arrangement to be superior to that employed by Marconi. The comparison, however, which the German writers and inventors at that date invariably insisted upon making was to take as typical of Marconi's methods the original single wire-aerial transmitter of Marconi, direct connected to one spark ball of the induction coil, the other ball being earthed.[37] Marconi had advanced far beyond this stage at the end of 1899 and beginning of 1900, and was already employing

[37] See remarks by Prof. F. Braun in *The Electrician*, March 15, 1901, vol. 46, p. 778.

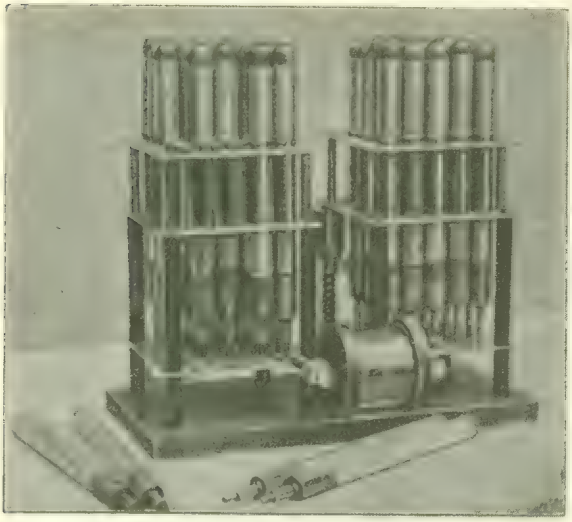


FIG. 51.—Leyden Jars or Condenser Tubes for Braun Transmitter.

FIG. 53.—Wehnelt Break.

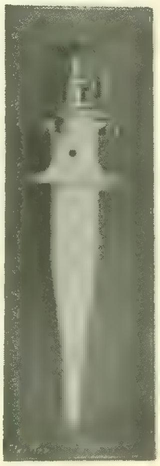


FIG. 54.—Adjustable Anode of Wehnelt Break.

Appliances used in the Transmitter Circuit of Braun - Siemens Electric Wave Telegraphic Apparatus.

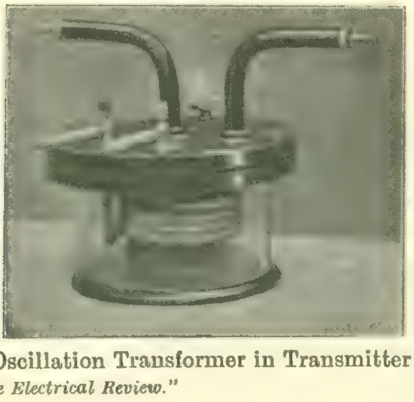


FIG. 52.—Oscillation Transformer in Transmitter Circuit.
From "The Electrical Review."

FIG. 55.—Arrangement of Braun-Siemens Wireless Telegraph Station.

FIG. 56.—Balancing Capacities used instead of Earth Connections in Braun-Siemens Transmitter and Receiver.

From "The Electrical Review."

the inductively coupled aerial with full knowledge of the conditions under which the best results could be obtained.[38]

15. The Telefunken System.—In the summer of 1903 the methods and inventions of Slaby, Von Arco, and the Allgemeine Elektricitäts Gesellschaft in Berlin, and those of Braun and Siemens and Halske, were amalgamated into a single company for conducting wireless telegraphy, and entitled the "Gesellschaft für Drahtlose Telegraphie," operating a system called the *Telefunken* system.

In the methods now adopted in this system there has been a return to the direct-coupled arrangement of the transmitter circuits and to telephonic methods of reception, as being in general more rapid than those employing a coherer and Morse printer. Also in

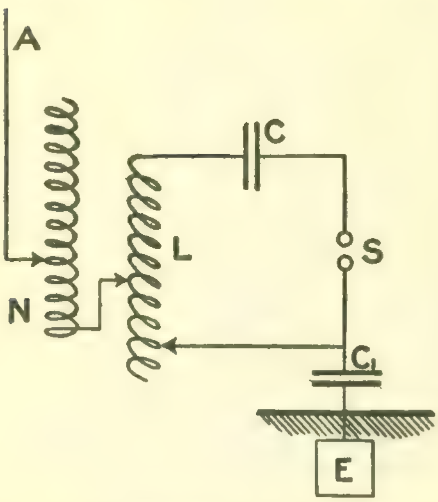


FIG. 57.—Arrangement of Apparatus in the Telefunken Transmitter. A, antenna; N, L, adjustable inductances; C, C_1, condensers.

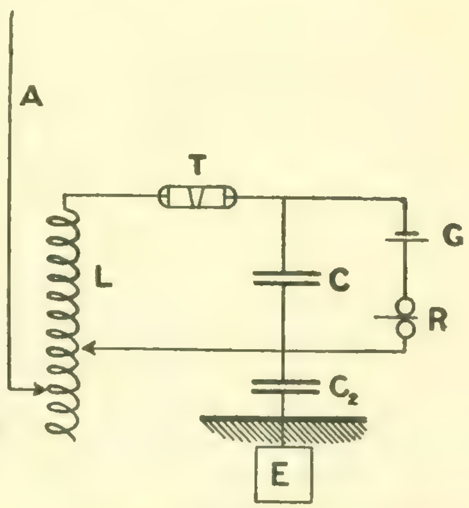


FIG. 58.—Arrangement of Apparatus in Circuit of Telefunken Receiver. A, antenna; L, adjustable inductance; T, coherer; R, relay; C, C_2, condensers.

most cases an earth connection is employed at the transmitting end. In some cases the simple earthed aerial with lateral extension is used as transmitter. In place, however, of a single pair of spark balls and a single spark gap a number of spark balls in series are employed, yielding a number of discharge sparks in series. In this manner large potentials can be employed and yet the dissipation of energy resulting from long sparks avoided, since the resistance of the spark increases very rapidly with its length. By this simple addition the Slaby-Arco transmitter is said to be capable of working over sea distances of 250 kilometres, with aerials only 32 metres high, and an energy expenditure of 90 watts in the induction coil.[39]

[38] We are not concerned here with questions of priority, but reference may be made to *The Electrician*, April 15, 1904, vol. 52, p. 1033, for a statement by Prof. F. Braun on his own work and his claims for it.

[39] See Otto Jentsch, "Telegraphie und Telephonie ohne Draht," p. 127. Berlin, 1904.

Also a direct-coupled aerial with closed condenser circuit is employed in this system. Variable inductance coils are inserted both in the condenser and aerial circuits for the sake of bringing the two circuits to resonance (see Fig. 57). The closed circuit is earthed through a large condenser. The receiving circuits used are of two types, one with a direct-coupled aerial (see Fig. 58), and another with an oscillation transformer inserted between the aerial and the closed circuit containing the wave detector (see Fig. 59). The cymoscope actually employed is either a metallic filings tube, having the bevelled plugs and filings enclosed in vacuum, or else an electrolytic detector, such as that of Schloemilch. If the metallic filings tube is employed, then the usual Marconi arrangements of tapper, relay, and Morse

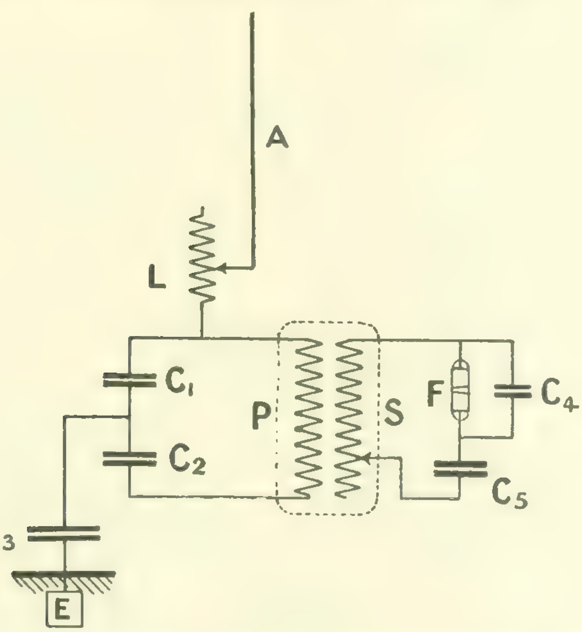


FIG. 59.—Alternative Arrangement of Apparatus in Telefunken Receiver. P, S, oscillation transformer; C_1, C_2, C_3, C_4, C_5, condensers.

printer are associated with it. If the electrolytic detector is used, then the telephonic method of reception is employed (see Fig. 60).

At the transmitting end an induction coil is used to charge the oscillating circuit. This is actuated by means of an alternating current, so that no interrupter is required. On board ship a rotating commutator is added so as to convert the ordinary continuous current used for the ship electric lighting into an alternating current having a frequency of about 50. In the primary circuit of the induction coil is inserted a Morse key, constructed as follows: The depression of the key brings together the platinum contacts, one on an elastic metal slip, M, carrying an iron armature and the other on the pole of an alternating electromagnet, E, through the coils of which the primary current of the induction coil flows. Hence, when the key is depressed this last circuit is closed and the attraction of the excited electromagnet on the armature keeps the circuit closed, even although the

key is raised (see Fig. 61). When, however, the alternating current passes through its zero value the armature flies up and the primary current is broken without spark.

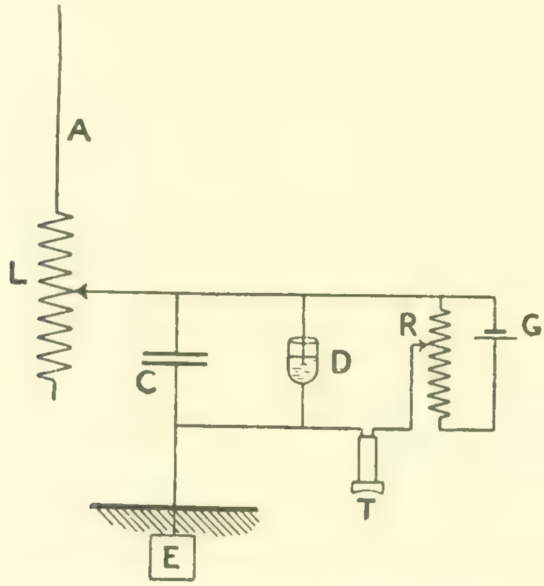


Fig. 60.—Telephonic Method of Reception as used in Telefunken System. A, antenna; L, adjustable inductance; D, electrolytic detector; T, telephone; G, battery; R, sliding resistance.

The oscillation transformer in the receiving circuit is "loosely coupled." Three types are employed, the secondary circuits being wound suitably for wave lengths of 50 to 200 metres, 200 to 600

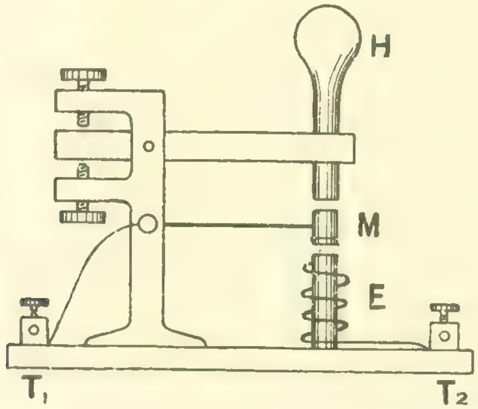


Fig. 61.—Non-sparking Key used with Alternating Currents in Telefunken Transmitter. E, electromagnet; M, intermediate contact.

metres, and 600 to 3000 metres, so that by change of connections the effective length of secondary circuit can be varied.

When the electrolytic detector is employed, the receiving circuit arrangements are as shown in Fig. 60.

16. Contributions of the Author to Wireless Telegraphy, 1900 to 1906.—The author's contributions to practical wireless telegraphy have consisted partly in the design of instruments for the exact measurement of electromagnetic waves of long wave length and in devices for their detection, and partly in improvements in apparatus for producing powerful electric waves by the discharge of large condensers, energized by means of alternating current transformers, connected to high tension alternators. One of these power wave generating arrangements is described in his British specification, No. 18,865, October, 22, 1900. In this arrangement an alternator, A (see Fig. 62), carries upon a prolongation of its shaft a revolving arm, x, insulated from the earth, and also an insulating cylinder or disc, D, having two contact plates laid upon a portion of its circumference. The revolving arm moves between two curved sectors, C_1, C_2, a knob

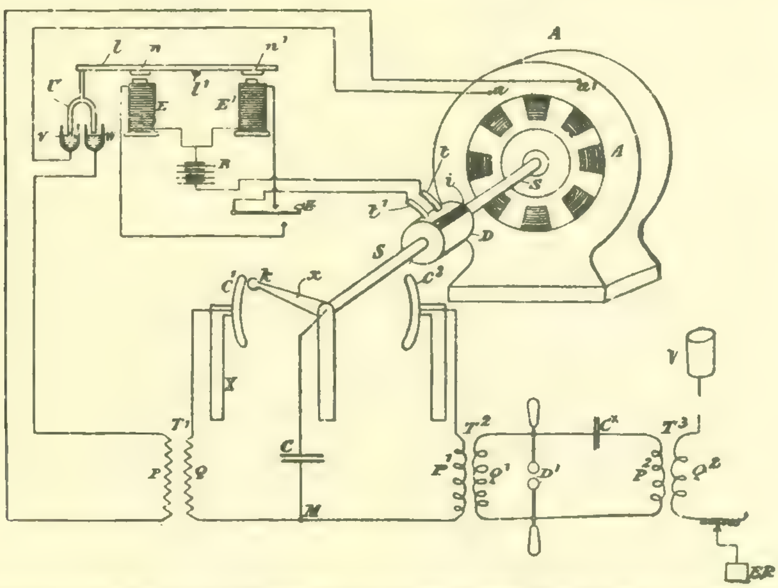


FIG. 62.—Rotating Arm Alternator and Transformer Plant for the Production of Powerful Electric Waves. (Fleming.)

at the end of the arm coming into close proximity to, but not touching, the curved sectors. An alternating current transformer, T_1, has its primary circuit, P, connected through a switch with the terminals of the alternator A, and its secondary circuit, Q, is connected by one terminal with the curved sector C_1, and the other to one surface of a large condenser, C, the corresponding surface of this condenser being connected to the central point of the revolving arm. The other curved sector, C_1, is connected to one end of the primary circuit of an oscillation transformer, T_2, the other end being joined to the condenser. The secondary circuit of this oscillation transformer is connected to a pair of spark balls. These spark balls are shunted by a second condenser, and the primary circuit to a third oscillation transformer, T_3. This last oscillation transformer has its secondary circuit connected in between an aerial wire, V, and an earth plate. The rotating arm X on the shaft of the alternator is fixed in such a position that just when

it comes to within touch of the curved sector C_1 the electromotive force of the alternator has its maximum value during one period. Hence if the transformer T_1 is a high tension transformer, under these circumstances a spark will jump across between the curved sector C_1 and the rotating arm X, and the condenser C will become charged. When the arm swings round into proximity with the other curved sector C_2, this condenser discharges itself through the primary circuit of the oscillation transformer T_2. The resulting oscillations charge the second condenser C′, and this in turn discharges across the spark balls with oscillations when its potential reaches a value corresponding with the length of the spark gap. Finally, oscillations are set up in the open circuit, and their energy radiated as electric waves. Signals are made by opening and closing the primary circuit of the alternating current transformer T_1. The purpose of the insulated cylinder on the shaft of the alternator is to prevent this opening and closing of the high tension transformer circuit during the time that the revolving arm is passing in front of the curved sectors. These curved sectors are such a length that the passage of the knob of the revolving arm over the sector is only a short fraction of the whole time of one half period of the alternating current, and takes place during the time that the electromotive force of the alternator is a maximum during the period.

The object of the insulating cylinder on the alternator shaft is to render it impossible to interrupt the charging of the condenser during the time the revolving arm is passing on its surface two curved plates of metal like an ordinary split tube commutator. Against this cylinder two metallic springs press, and these are therefore put into electrical connection when the springs are both touched by a metal part, but are disconnected when both are resting on an insulating portion of the cylinder. These springs are in series with a battery, key, and electromagnet. This electromagnet operates a mercury or other contact key, which opens and closes the primary circuit of the high tension transformer. The cylinder is so set on the shaft of the alternator that the operator, by pressing the hand key K, can tilt backwards or forwards the main key U. This last key, however, cannot be moved during the time of passage of the arm x in front of the sectors, but only during the remainder of a revolution of the arm. The locking of the main key in this manner is required to prevent the possibility of damage to the high tension transformer or condenser by suddenly interrupting a large current when it is flowing into the condenser. The performance of the plant is as follows: At each revolution of the alternator, which may occupy 0·05 of a second (corresponding to 1200 revolutions per minute), the first condenser is charged and discharged with oscillations. As this condenser is one of large capacity, say 1 mfd., these oscillations are, relatively speaking, slow. They may have a frequency as low as 100,000, or less. These oscillations are very slightly damped, as the spark resistance in the discharge circuit is very small and the circuit is non-radiative. At each of these oscillations the second condenser is charged, and as the capacity of this last condenser is much less than that of the primary condenser, its oscillations through its own spark gap and the primary of the oscillation transformer T_3, have a much higher frequency.

To secure the best result, however, the circuit composed of the condenser C′, the primary of the transformer T_3, and the secondary of the transformer T_2, must be tuned by the insertion of inductance, so as to have the same time period as the discharge circuit of the main condenser C. The spark balls D′ can then be set at such a distance apart that the voltage on the secondary terminals of the transformer T_2 cannot *per se* make a discharge across the gap, but the discharge is only brought about when resonance has so exalted the potential difference of the condenser C′ that it is able to discharge across the gap with oscillations. Hence we have a discharge of the condenser C′ taking place, not at every oscillation of the condenser C, but at every few oscillations. Nevertheless, the result is that the groups of oscillations resulting in the aerial circuit are far more numerous and of far greater amplitude than those taking place in the main con-

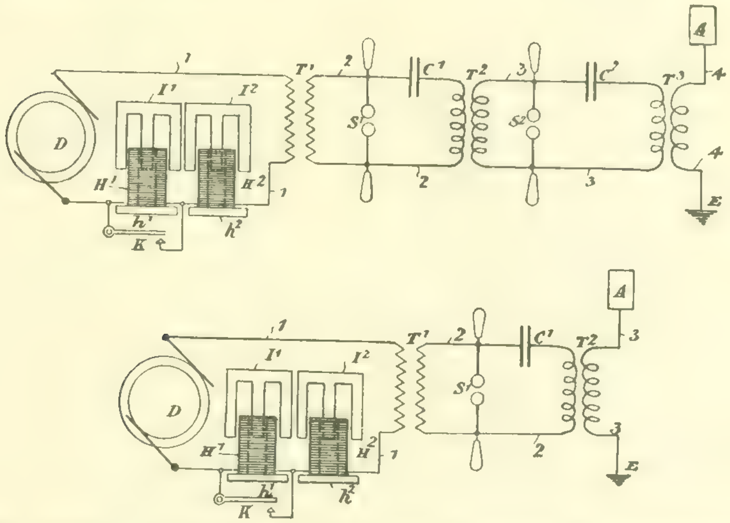


FIG. 63.—Alternator Transformer and Condenser Plant with Multiple Oscillation Transformers and Spark Gaps for the Production of Powerful Electric Waves. (Fleming.)

denser circuit. We are thus able to step-up the potential, and to step-up the group frequency and also the frequency of the individual oscillations in the groups, and obtain a very energetic radiation consisting of wave trains extremely close together.

Similar arrangements can be carried into effect employing a high tension continuous current dynamo.

In a subsequent specification, No. 3481 of February 18, 1901, the author described a simpler and yet more powerful arrangement for generating energetic electromagnetic waves.[40] In this arrangement a high tension alternator, A (see Fig. 63), has its terminals connected to the primary circuit of one or more alternating current transformers, T_1, which may be arranged with their primary circuits in parallel or series. It is usually most convenient to employ an alternator having an electromotive force of 2000 volts, and to employ a battery of high

[40] The equivalent United States Patent is No. 758,004, applied for April 8, 1901, dated April 19, 1904.

tension transformers raising voltage from 2000 to 30,000 volts. The primaries of these transformers may be joined in parallel on the alternator terminals, and the secondary circuits may be joined in series, so as to add together the potentials of the transformers. In the circuit with the alternator and the transformers are placed two coils of high inductance, H_1, H_2, which are provided with E-shaped iron cores, capable of being lowered down into these bobbins, so as to increase their inductance. One of these bobbins is short-circuited by a key, K. The secondary terminals of the alternating current transformer T_1 are connected to a spark discharger, S_1, the balls of which are shunted by a condenser, C_1, and the primary circuit of an oscillation transformer, T_2. A similar inductive coupling is then repeated with another condenser, C_2, spark ball, S_2, and oscillation transformer, T_3. The secondary circuit of this last transformer is finally connected to an aerial, A, and an earth plate, E. The operation of the arrangement is as follows: One of the choking coils, H_1, is short-circuited by the key K, and the iron core I_2 of the other choking coil H_2 is lowered into such a position that its impedance permits not more than the maximum full load primary current to flow into the transformer T_1 when the balls S_1 are short-circuited. The iron core I_1 of the choking coil H_1 is then lowered down into the coil, and if the key K is then raised the impedance of the choking coil H_1 will stop all current from flowing into the transformer T_1. When these arrangements have been made, the balls S_1 are set up such a distance apart that an alternating arc discharge will not take place, due to the mere secondary electromotive force of the transformer T_1 working alone without the condenser shunt circuit. The spark gap is thus made greater than that corresponding to the normal maximum voltage of the high tension transformer working alone. If, then, the condenser C_1 and oscillation transformer T_2 are connected to the spark balls S_2, as shown in the drawing, and the other connections also completed, we have three circuits inductively connected with one another. In the first place, there is the circuit of the alternator and the primary of the high tension transformer T_1. In this circuit we have an alternating current flowing, the frequency of which is determined by the speed and construction of the alternator. It is possible to arrange the inductance and capacity of the circuit composed of the condenser C_1, the primary circuit of the oscillation transformer T_2, and the secondary circuit of the high tension transformer T_1, that this circuit is in resonance with the alternator circuit. When this is the case, the alternator current will create a powerful secondary current in the condenser circuit, and the potential between the spark balls S_1 will accumulate to such a value that a discharge takes place across the spark balls. The condenser C_1 then discharges with oscillations, and these oscillations are transformed up in potential by the oscillation transformer T_2, and set up secondary oscillations and discharges in the circuit composed of the condenser C_2, the spark ball S_2, and the primary of the oscillation transformer T_3. Finally, these give rise to powerful high frequency oscillations in the aerial circuit, which throw off their energy in the form of electric waves. This result, however, is only secured when the several circuits thus inductively coupled are in resonance with each other.

The whole of the discharges are under perfect control by means of the key K, and when this key is up the impedance of the choking coil H_1 prevents any sensible current from flowing through the transformer T_1. When the key is down the oscillatory discharges succeed one another with great rapidity, hence they can be cut up into dots and dashes in accordance with the Morse code. The same specification provides numerous details of the construction of these transformers, and also of the condensers employed.

It is desirable that the condensers be arranged in parallel between two conductors, so that for each component condenser of the battery of condensers the length of circuit through which the discharge takes place is exactly the same. This arrangement is an exceedingly powerful arrangement for producing rapid trains of electric waves by multiple transformation of electric oscillations in circuits which are brought into resonance with each other.

In a British patent specification (No. 20,576, of November 14, 1900) the Author described another method of controlling the oscillatory discharges so as to cut them up into signals by means of a

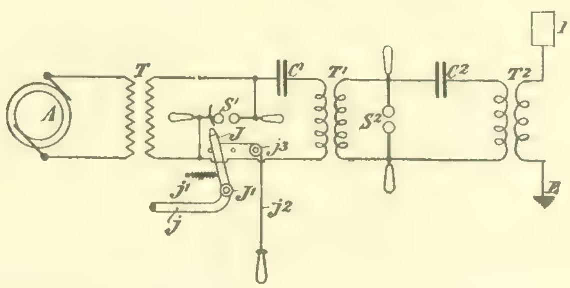


FIG. 64.—Method of Signalling by adjustable Air Blasts impinging on the Spark Balls. (Fleming.)

movable or directed air blast, as shown in Fig. 64.[41] A tube, J, from which an air blast is proceeding, is hinged so that the air blast can be directed between the spark balls, across which a condenser is discharging. These balls are set at such a distance apart that when the air blast is not directed on them the high tension transformer T creates an alternating current arc between the balls S_1, but no oscillations take place in the condenser circuit shunted across the balls. On directing the blast against the spark balls, the alternating current arc is blown out and an oscillatory discharge takes place.

By interrupting the air blast either by a valve in the pipe or by moving the nozzle, the oscillatory discharge can be created for long or short periods, as required, to make the signals of the Morse alphabet.

In another British patent specification (No. 22,126, of December 5, 1900) the Author described a similar multiple oscillation circuit, but the control of the oscillations was achieved by inserting in the circuit of the alternator and first transformer another regulating transformer, the secondary circuit of this regulating transformer being closed on

[41] The equivalent United States patent is No. 758,005, applied for April 8, 1901, and dated April 19, 1904.

water resistances, W_1, W_2, consisting of plates immersed in vessels of water. As long as the secondary circuit of this regulating transformer is open, its primary circuit offers such impedance to the flow of the current from the alternator, that no current passes through the primary circuit of the high tension transformer T sufficient in magnitude to charge the condensers connected with the secondary circuit of this last transformer. If, however, a key, K, in the secondary circuit of the regulating transformer is closed, then current at once flows through the high tension transformer T sufficient to charge the condenser C and create the oscillatory discharges.

It will be seen that the devices described in the above three mentioned British specifications, Nos. 20,576 and 22,126 of 1900, and 3481 of 1901, amongst other things, are for means of controlling the current flowing through the primary circuit of the battery of high tension transformers without at any time opening the said primary circuit.

Another arrangement of the said type described by the author in his British patent specification, No. 24,825 of 1901, is for an arrangement in which oscillations of different frequency can be created simultaneously in two aerials associated with one and the same oscillatory circuit actuated by some high tension transformer and alternator. In this manner two sets of waves of different wave length can be radiated simultaneously, sending different messages and received upon different receivers at the same or different places.

Another invention of the author in connection with transmitting apparatus is for a discharger (see British specification, No. 25,383, of November 20, 1903, or United States patent, No. 792,014), consisting of balls which are set in revolution by electric motors or other means, and included in a chamber in which nitrogen or carbonic acid gas is compressed.

The balls or discs between which the discharge takes place are driven round at a slow pace by means of gearing, which in turn is driven by a small electric motor or clockwork (see Fig. 65). When electric motors are employed, each ball or disc is preferably driven by its own motor, and these motors are contained in a cast or wrought iron sound-proof chamber, which also contains the ball discharger. As the contact surfaces are continually being changed they wear more evenly, and the kind of spark, therefore, required for the performance of electric wave telegraphy is better preserved. If these balls or discs are hollow, water may be caused to circulate through them and so keep them cool. It is found that a very great advantage is secured by using a short spark taken in compressed nitrogen enclosed in a strong iron reservoir, as the electric discharge can be made perfectly noiseless, and the unpleasant effects arising from this sound are obviated. In order to make the contact between the revolving ball or disc and the external electrical generator (whether it be a transformer, induction coil, or any other means), mercury cup contacts are used. The shaft carrying the ball or disc has on it a copper cup containing mercury, and a stout copper pin connected with the external circuit dips into this mercury. The disc can, therefore, revolve, and yet a good connection is kept up with the external circuit. Otherwise the mercury cups are connected with the external

circuit, and a copper disc or pin on the revolving shaft which carries the balls dips into the mercury in this fixed cup.

If the discharger is enclosed in an air-tight reservoir containing compressed gases, then the rods or cables coming from the generator must pass air-tight through the sides of the reservoir by means of glands. The screws also serving to alter the distance of the balls or discs must in the same way pass air-tight through the sides of the reservoir.

In Fig. 65 a is a cast-iron ball, say about 6 inches in diameter, which is traversed by a copper shaft, b, having a hard steel point, b', on the bottom end, and the top end having in it a steel pin, b^2, entering the cup formed in the top of the ball. Each ball is supported upon a

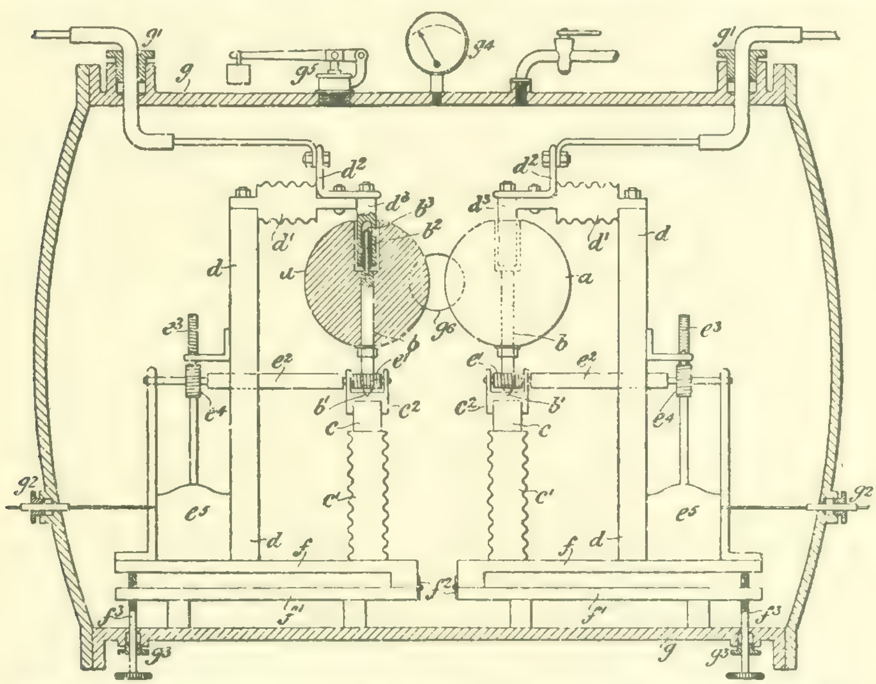


FIG. 65.—Rotating Ball Discharger Working in Compressed Nitrogen. (Fleming.) a, a, rotating spark balls; e^5, electric motors; f, f, tilting tables for varying spark length; g^1, g^1, discharge circuit leads.

wooden bridge, c, on ebonite insulators, c', carrying a brass sole plate, c^2, in which there is a recess for the steel point b' to rest. The ball is sustained in an upright position in the following manner: d, d are two stout wooden uprights, which carry horizontal corrugated ebonite insulators, d'. These ebonite insulators carry a transverse copper strip, d^2, having attached it to a copper pin, d^3. This copper pin has a longitudinal hole bored in it to receive the steel pin b^2, and in order to prevent metal to metal contact, a glass tube, b^3, is slipped over the pin b^2. The cup in the top of the ball is then filled with mercury. In this manner the ball is connected electrically by a very good joint with the copper strip d^2, which is the terminal of the instrument, and yet the ball itself is free to revolve quite easily. The ball is driven round by an electric motor in the following way: On the lower end

of the shaft b is fixed a worm wheel, e, which engages with a worm, e', on an insulated shaft, e^2, of ebonite. On the shaft e^2 is a second worm wheel, e^3, driven by the worm e on the shaft of the motor e^5. The whole arrangement is carried upon a platform composed of two boards, f, f', jointed together by hinges, f^2. The upper board f can be tilted by screw f^3, so that by tilting the two tables which carry the two halves respectively of the discharger, the balls can be brought nearer to or moved away from one another, so as to vary the spark gap.

This apparatus is enclosed in a sheet-steel or cast-iron drum, g, sufficiently large to contain the whole discharger conveniently, preferably constructed like a small cylindrical boiler.

In this boiler there is a pair of glands or stuffing boxes, g', through which the cables are brought air-tight to the copper strip d', and also two glands, g^2, for the cables, conveying the current and driving the small motors e^5. Stuffing boxes, g^3, are also provided for the screws f^3. In this manner the balls can be driven round in an air-tight chamber into which nitrogen or carbonic acid can be pumped under pressure.

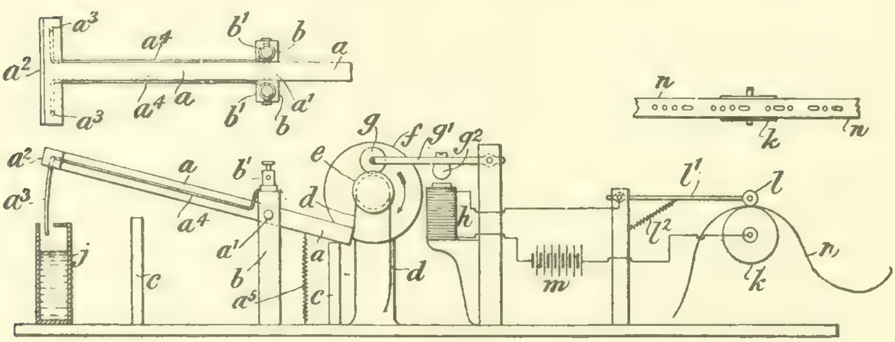


FIG. 66.—Automatic Signalling Key for High Tension Alternator Circuit operated by Punched Tape. (Fleming.)

As the action of the electric spark is to combine together the oxygen and nitrogen of the air producing nitric acid, it is better to employ nitrogen instead of air.

It is desirable, therefore, to provide the closed chamber with a pressure gauge, g^4, and a safety valve, g^5, so that a stated pressure may not be exceeded. In this closed chamber or iron boiler there should also be a small peep hole, g^6, closed with a stout glass plate to enable the spark to be inspected.

Another of the Author's devices is a signalling key operated by a punched tape (see British specification, No. 25,382, of November 20, 1903, or United States specification, No. 792,015). The object of this invention is to actuate the key employed to short-circuit the choking coils described in the transmitting arrangement covered by the British specification, No. 3481 of 1901. For this purpose a key is used which effects the required short-circuiting by immersing in a mercury vessel two prongs carried on the end of an arm (see Fig. 66). A light wooden arm, a, is pivoted on a fixed stand, and carries two wires, which are connected respectively to two fixed terminals. These wires end in curved branches, which are immersed

in a vessel of mercury, *j*, when the arm is depressed, thus connecting or short-circuiting the choking coil terminals. The switch terminals are connected by wires with the choking coil H in the arrangement above mentioned. The movement of the arm is effected in the following manner: The shorter end of the arm carries a tape, *d*, which lies over the pulley of a rapidly revolving electric motor. A jockey pulley, *g*, rests upon this tape, the said jockey pulley being carried at the end of a pivoted arm, to which is also attached an iron armature situated near the poles of an electromagnet, *h*. When the circuit of this electromagnet is closed, the armature is drawn down, and the jockey pulley presses the tape against the pulley of the revolving motor, causing it to grip and be wound up as far as it will go. The short end of the arm is then raised, and the long side depressed, thus immersing the curved wires in the mercury vessel.

The electromagnet is energized by means of another battery, the circuit of which is closed through two wheels. One of these is a wide pulley, on which the perforated paper tape, *n*, is made to travel by means of clockwork, and the other wheel is a small platinum disc, *l*, which drops through the holes punched in the paper tape and makes contact with the larger wheel, thus completing the magnet circuit at intervals and for times corresponding to the holes punched in the tape in accordance with the Morse signals. This arrangement permits of the rapid and certain operation of the key, the function of which is to short-circuit the choking coils in the arrangement described in Fig. 63, and so create the oscillations in the multiple transformer circuit. Any message can be punched in section lengths of paper tape, and these fed through the transmitter in proper order. In transmitting code messages, this automatic sending key is of great value, as the spacing of letters and words is accurately kept, whatever the speed of transmission.

The author's inventions in connection with the measurement of long electric waves and the conversion of electric oscillations into continuous currents by means of an *oscillation valve* have already been described in Chap. VI.

17. Electric Wave Wireless Telegraphy in the United States.—Practical work in wireless telegraphy by electromagnetic waves in the United States is mainly connected with the names of R. A. Fessenden, Lee de Forest, J. S. Stone, and a few others, although most valuable work has been done by purely scientific investigators such as Professor G. W. Pierce.

The record of this work is chiefly to be found in the bulky volumes of United States patent specifications. These documents are often elaborate treatises on the subject, abounding in references to the literature and present "state of the art."

It is a matter of the greatest difficulty in reading these specifications to separate out the wheat from the chaff and distinguish that which is really new and useful from that which is simply an effort to disguise old knowledge in a new form.

For the purposes of this treatise, it will be sufficient to mention the principal specifications of the chief workers, with a few words of comment describing their contents, and leave the reader to make

further acquaintance with them if desired, in the volumes in the Patent Office Library.

18. Work of R. A. Fessenden.—The extensive and practical work of Professor R. A. Fessenden on wireless telegraphy commenced in connection with the United States Weather Bureau at Washington, and continued in connection with the National Electric Signalling Company of U.S.A., has been directed to the invention of wave detectors, appliances for producing continuous trains of electromagnetic waves, methods for increasing wave energy and wave length, and devices for achieving the isolation or syntonization of wireless telegraph stations and methods of conducting wireless telephony.

The following list of United States patents granted to him includes those in which his chief contributions to the subject are specified.

No. 706,735 and No. 706,736, applied for December 15, 1899.—These specifications cover a dynamometer detector for electric waves. Starting from the fact discovered by the author of this treatise in 1887, that a ring or disc hung at an angle of 45° to the plane of fixed coils is caused to deflect when an alternating current passes through the coils, Fessenden applied this principle in the construction of a device for detecting electrical oscillations. A light suspended silver ring with attached mirror is placed obliquely between two fixed coils, which last are in the circuit of the receiving aerial. The oscillations set up in the aerial, and therefore in the fixed coils, create induced currents in the ring and cause it to deflect. This form of receiver, is useful in metrical work as shown by Professor G. W. Pierce, but is not sensitive enough for long-distance practical wireless telegraphy.

These specifications also include diagrams and descriptions of a transmitting arrangement consisting of a Marconi aerial wire, spark balls, and earth connection, but a condenser shunted across the spark gap to maintain sustained radiation. It is stated that the shunt circuit must be tuned to the receiving conductor otherwise the oscillations produced by it will have no action on the wave responsive device at the receiving circuit. It was subsequently asserted by the patentee that the sixth claim of No. 706,735 and the twenty-sixth claim of 706,736 covered the invention of the local oscillatory circuit and an antenna tuned to it (see *The Electrician*, February 15, 1907, Vol. 58, p. 675, 1907).

No. 777,014, applied for June 2, 1900.—This contains a description of an elaborate apparatus for generating two or more series of electric waves, and recording at each receiving station only such series of waves as are sent out in a particular order. Its purpose is to obtain privacy in the telegraphy. With this object he employs several sending and receiving aerials, and the apparatus is so arranged that to produce a telegraphic *dot* or *dash* at the receiving station requires the conjoint action of waves from all the sending wires, and these are caused to perforate at the receiving station telegraphic paper, which then passes through a recording apparatus. This last records a dot or dash only when certain properly spaced perforations are made on the telegraphic tape by the conjoint action of the group of waves sent out from the transmitter. The apparatus in principle somewhat resembles that developed later by Anders Bull.

No. 706,737, applied for May 29, 1901.[42]—This is a patent for the construction of an aerial consisting of a number of wires, grouped in cylinder fashion, to construct an aerial of large capacity. The patentee points out that if such an aerial is associated with an inductance and a high frequency alternator directly, the

[42] The equivalent British specification is No. 17,708, of August 12, 1902.

alternator having one terminal to the aerial and the other earthed, no spark gap being used, it would radiate very long electric waves. Two reissues Nos. 12,168 and 12,169 were applied for on October 20, 1903. This specification, however, is chiefly important in that the patentee clearly describes the necessary characteristics of a high frequency alternator for radiotelegraphic work.

No. 706,738, applied for May 29, 1901.—This covers various forms of sending and receiving aerial of large capacity.

No. 706,739, applied for May 29, 1901.[43]—This patent covers devices for clothing or surrounding the sending aerial with media, having large dielectric constant and considerable permeability. The patentee desired to create long electric waves with short aerials, and he considers that he can do it by packing round the aerial with dielectrics such as paraffin, pitch, indiarubber, or other dielectrics having iron filings embedded in it. The author is not aware that the process has been tried, and in any case it would probably result in considerable absorption of the energy of the oscillations. The suggestion is based upon the optical fact that when a wave of light emerges from a material of high refractive index into one of smaller, the wave length is increased proportionately to the velocity, since the frequency must remain the same.

No. 706,740, applied for September 28, 1901.[44]—This is for a system of electric wave telegraphy in which two or more radiators are employed to send out persistent or undamped waves of different wave length, and at the receiving station a corresponding number of receiving aerials are employed, and a receiver which cannot operate except in virtue of the conjoint action of all these waves of different wave length. The coherer or cymoscope placed in the receiving aerial circuit is not acted upon by either wave train separately, but only by the sum or difference of their actions on the receiving aerials.

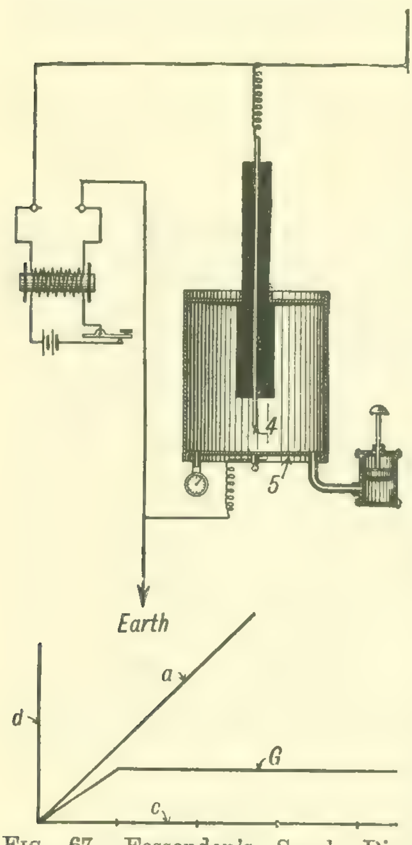


FIG. 67.—Fessenden's Spark Discharger using Compressed Air.

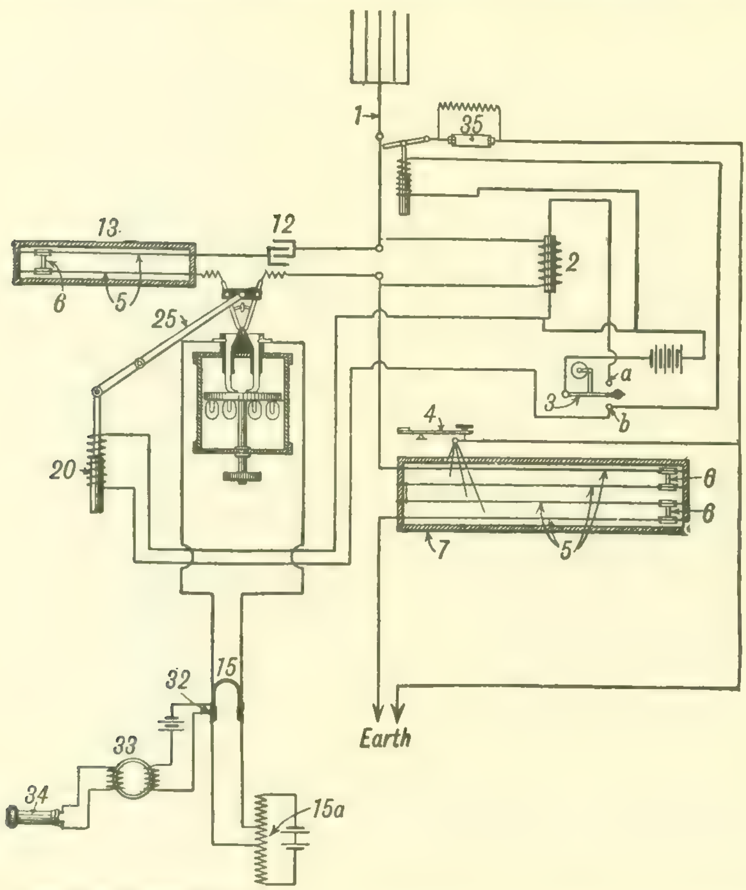
No. 706,741, applied for November 5, 1901.—This specification covers devices for creating the oscillatory spark in the wave-generating circuit in the interior of a vessel in which air or other gases is compressed. The inventor prefers to take the spark discharge between a plate, 5, and a point, 4 (see Fig. 67). He states that the terminals are to be adjusted about 0·26 inch apart, and that as the pressure of the gas increases the dielectric strength is raised to almost any extent without material loss in oscillatory power, whereas in air at ordinary pressure increasing the voltage beyond that sufficient to give a 1-inch spark in air results in no increase in radiation. He also states that if we employ a constant spark voltage and raise the gas pressure, then the corresponding spark length is reduced as the pressure rises, but that up to fifty pounds pressure on the square inch no marked increase in the electric radiation takes place. If, however, the pressure is increased beyond sixty pounds, the patentee states that the radiation begins to increase, and at eighty pounds is about three and a half times that at fifty pounds, and becomes, moreover, substantially proportional to the potential of the source of supply. This result may be brought about by the much greater

[43] The equivalent British patent is No. 17,703, of August 12, 1902. The reader may compare this specification of Fessenden's with those of J. S. Stone, Nos. 717,511 and 717,512, applied for January 23, 1901.

[44] The equivalent British patent is No. 17,704, of August 12, 1902.

suddenness with which the highly compressed gas yields under electric stress when the disruptive voltage is reached.

No. 706,742, applied for June 6, 1902.[45]—In this specification the patentee describes the complete arrangement of transmitter and receiver for utilizing the thermal receiver already described, constructed with a fine platinum wire in a vacuous bulb. The transmitting arrangement consists of a multiple aerial, 1 (see Fig. 68), having the spark balls at its base connected to the secondary terminals



From "The Electrician."

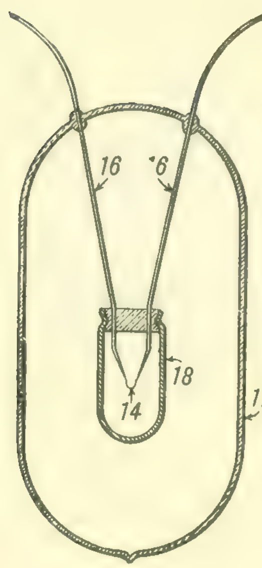
Fig. 68.—Diagram of Connections in Fessenden's Receiving Apparatus for Electric Wave Telegraphy.

of an induction coil. The lower spark ball is connected to the earth through an adjustable inductance consisting of parallel wires placed in a vessel of oil, the effective length of these wires being variable. The receiving arrangement consists of a circuit including a condenser, 12, and a variable inductance, 13, and also one of the wire barretters or thermal receivers already described (see Chap. IV.; see also Fig. 69). As these fine loops of wire are easily destroyed by any excessive oscillations, an arrangement is provided by which a new loop can be

[45] The equivalent British patent is No. 17,705, of August 12, 1902.

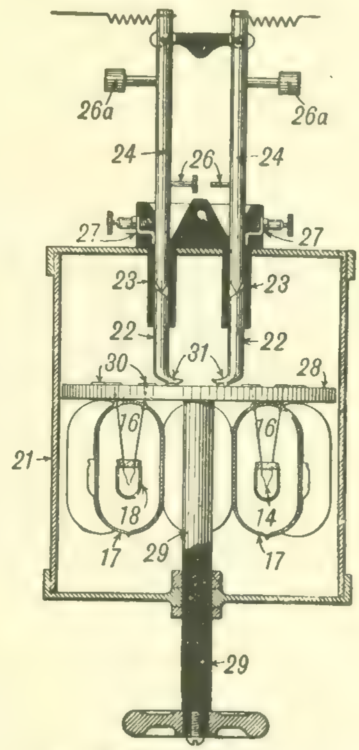
quickly substituted for a burnt-out one (see Fig. 70). The thermal detector is connected in between the aerial and the earth when it is desired to receive. The effect of the electric waves impinging on the receiving aerial is to create oscillations which heat the very fine wire of the barretter and increase its resistance.

To detect this increase in resistance, the barretter is also joined into a circuit which includes a telephone and a shunted voltaic cell. When the resistance of the barretter is suddenly increased by the rise in temperature, the current through the telephone is suddenly



From "The Electrician."

FIG. 69.—Fessenden Hot-wire Receiver or Barretter, consisting of a fine loop of platinum wire (14) enclosed in a bulb (18).



From "The Electrician."

FIG. 70.—Fessenden's Arrangement for working Barretters in Parallel or making Changes.

varied, and a sound is heard, long or short, according to the duration of the wave trains, thus signalling a *dash* or *dot* on the Morse code.

The same specification contains elaborate instruction for making the fine platinum wire loops and mounting them in bulbs to make the barretter; also descriptions of the keys and sliding inductances employed.

In this specification No. 706,742 Fessenden describes a method of producing oscillations in the antenna by means of continuous currents. A continuous current dynamo has its terminals connected to the balls of a spark gap, which balls are also connected respectively to an antenna and to the earth and also shunted by a condenser and inductance. A variable resistance is interposed between the spark

balls and the dynamo. It is asserted that by proper adjustment of the resistance an intermittent discharge may be obtained between the balls.

This method was subsequently described by the patentee as a method of producing oscillations in the antenna by means of an electric arc and claimed as an improvement on Elihu Thomson's method of producing sustained oscillations although no proof is given in the specification that either method did actually succeed in producing true persistent and undamped oscillations (see *The Electrician*, Vol. 58, p. 676, 1907).

No. 706,743, applied for June 26, 1902.—This describes a method of recording the signals given by a hot-wire barretter on a photographic paper band and developing the same.

No. 706, 744, applied for June 6, 1902.—Gives further details of the process of making the platinum wire barretter or thermal receiver. Since one single loop is very fragile, a number of such barretters may be joined in parallel. This does not decrease the sensitiveness of the receiver as a whole, since the reduction of resistance is accompanied by a reduction in inductance of the whole of the loops taken together, and hence a greatly increased oscillation current results, which causes the percentage change in resistance to be about the same for many as for one single loop.

No. 706,745, applied for July 1, 1902.—This specification covers a description of a number of receiving devices and the best mode of employing them, and distinguishes between those modes which are useful when using potential actuated devices, such as a coherer, and those when using current actuated devices, such as a thermal cymoscope. The patentee draws a comparison between the sensibility of a coherer and his thermal receiver, stating that with the latter messages at the rate of thirty words per minute were sent and received over a distance of fifty miles, using a spark at the sending end 0·03 inch in length, whereas with the same arrangement he says a spark 5½ inches had to be employed when using a coherer. This, however, only shows that under the circumstances of the comparison the coherer was being used in a very disadvantageous manner, and the comparison is not an equitable one.

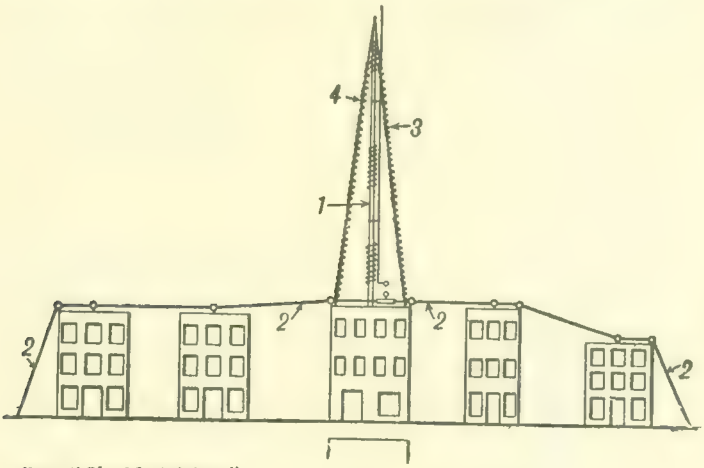
No. 707,746, applied for July 1, 1902.[46]—The patentee describes in this document an arrangement which he calls a wave chute (see Fig. 71). This appears to consist of an extensive wire netting, which is connected to the earth plate at the base of the aerial, and spreads over any buildings which may be in its neighbourhood.

No. 715,043, applied for August 27, 1902.[47]—This specification covers the description of a form of magnetic cymoscope or wave detector. A ring-shaped core of iron wires is wound over with two circuits, and these circuits are connected to a two-phase alternator so as to produce a rotating field in the interior of the core. We may regard this rotating field as produced by the slow movement round the ring of a series of magnetic poles. Owing to the hysteresis of the iron, the induction in the core lags behind the magnetizing force. The ring is wound over in addition with a solenodial winding which is in connection through an air core transformer with the receiving aerial. When oscillations are set up in the aerial by the impact of

[46] The equivalent British patent is No. 17,703, of August 12, 1902.
[47] The equivalent British specification is No. 26,553, of December 2, 1902.

electric waves, the induced oscillations travel round the iron, annul its hysteresis, and the induction in the core makes a sudden movement up into step with the magnetic force. The interior of the ring is surrounded by two coils at right angles to one another, which are connected with the windings of a magnetic telephone, small condensers being interposed. The slow movement of the flux travelling round the space does not therefore affect the telephone, but any sudden movement due to oscillations occurring in the demagnetizing coil causes a sound in the telephone, hence the arrangement serves to detect oscillations in the aerial, and therefore waves falling upon it.

No. 727,331, reissue No. 12,115, application for reissue filed May 5, 1903.—This specification relates to the "liquid barretter" or wave responsive device of the type claimed in U.S.A. patent, No. 706, 744. Fessenden found that if a very thin wire of platinum was placed in an electrolyte such as nitric acid, and if the wire was broken in the middle, it acted as a wave responsive device. He was thus led to



From "The Electrician."

FIG. 71.—Fessenden's Wave Chute.

the invention of what is now called the electrolytic detector in which a metal plate and a short length of very fine wire are immersed in an electrolyte, and when this electrolytic cell is placed in series with a small continuous voltage and a current detector such as a telephone it becomes responsive to feeble electric oscillations as described in Chap. VI. This patent was upheld by Judge Wheeler in the U.S.A. Circuit Court of the Southern district of New York when sued upon by the National Electric Signalling Company *v.* the De Forest Wireless Telegraph Company in 1905.

No. 730,753, applied for April 9, 1903.—This specification relates to improvements in the apparatus described in the United States patents, Nos. 706,735, 706,736, 706,737, 706,747, and 727,325. It has reference to methods for producing continuous trains of electric waves by means of alternators or continuous current dynamos. In the particular arrangement described in this specification, the patentee proposes to pass the current from a continuous current dynamo through a high resistance, and to charge by means of it some condenser to a sparking potential. Since the condenser takes time to charge through the resistance, it rises up to

a certain potential and then discharges again. The discharge of the condenser sets up oscillations in an associated aerial wire. The patentee takes pains to prove that this arrangement was not anticipated in the United States patent, No. 550,630, granted to Elihu Thomson.

No. 731,029, applied for May 4, 1903.—This specification covers forms of liquid barretter, of the type previously described in the United States patent, No. 706,744, granted to R. A. Fessenden, August 12, 1902. The patentee describes five or six methods for constructing a liquid resistance which changes its resistance under the action of electric oscillations. He finds that a liquid, such as dilute sulphuric acid, is preferable to a fine wire made of platinum, since the change in resistance of platinum is only about 0·33 per cent. per degree Centigrade, whereas the change in resistance of the dilute sulphuric acid may be as much as 12 per cent. per degree Centigrade. He gives several methods for forming a *liquid barretter*, to which reference has already been made. The one to which preference is given consists of a very fine platinum wire immersed to a small depth in nitric acid, the thin platinum wire being prepared by the Wollaston process, and the silver dissolved off to the required extent by immersing the compound wire in the nitric acid.

As has already been pointed out, the action of this liquid barretter, which Fessenden asserts is due to a thermal action, may be explained as due to an annulment of the electrolytic polarization by the electric oscillations.

No. 12,115, reissued letters patent, corresponding to No. 727,331, dated May 5, 1903.—This is a reissued United States patent which refers to the above-described liquid barretter.

No. 752,894, applied for December 29, 1902.—In this specification the patentee describes a form of receiving arrangement which is not affected by individual oscillations, but only by groups of oscillations, with the object of obtaining an arrangement insensitive to stray or undesirable waves, but only affected by groups of waves sent out at regular intervals from a station intended to be in syntony with that particular receiver. Very much the same device had previously been described by Blondel.

No. 752,895, applied for March 14, 1903.—This specification describes a method of preventing interference by external disturbances by the use of an auxiliary or neutralizing antenna, such that the effect of the waves it is not desired to receive is annuled by their counter-action upon the two antenna, but the waves it is desired to absorb do not so affect both antennæ.

No. 753,863, applied for September 28, 1901.—This is one of the earliest specifications for wireless telephony. The patentee proposes to employ undamped or nearly unintermittent traces of oscillations and to modulate their amplitude by means of a microphone and so radiate from an antenna waves which represent in amplitude the wave form of speech. These are to be received by another antenna and made to affect a telephone receiver. Fessenden had at this date clearly enunciated the essential principles of radiotelephony.

No. 753,864, applied for October 1, 1903.—This is for a horizontally extending antenna, but nothing is said about its directive quality.

No. 754,058, applied for August 8, 1903.—This is for a high speed turbine-driven alternator for producing high frequency undamped oscillations. He refers to a high frequency alternator in his U.S.A. patent No. 706,737, which he says gave a frequency of 20,000 and had an efficiency of 80 per cent.

No. 777,014, applied for June 2, 1900.—This specification contains a description of a method of isolating stations by sending groups of waves spaced in a certain manner. The receiver is only affected by the arrival of this special group of trains of waves, but not otherwise. The method has a similarity to that devised by Anders Bull.

No. 793,647, applied for December 14, 1904.—This is for improvements in capacities made with sections of insulated cable.

No. 793,648, applied for December 14, 1904.—A liquid barretter with compressed air, 40–50 lbs. per square inch, in the containing vessel, whereby the signals are said to be improved.

No. 793,649 and No. 793,750, applied for March 30, 1905.—These are specifications of Fessenden covering methods for radiotelephony.

No. 793,651, March 30, 1905.—A condenser for wireless telegraphy consisting of metal plates placed in a vessel containing air under great pressure, also for methods of constructing and supporting large antennæ.

No. 793,652, applied for April 6, 1905.—This specification describes means for sending and receiving messages simultaneously by connecting the antenna alternately to the sending and receiving circuits.

No. 793,718, applied for March 30, 1905.—The use of a water jet as an antenna.

No. 793,777, applied for March 30, 1905.—A detailed description of a condenser for radiotelegraphy consisting of metal plates in a vessel containing compressed air or gas.

No. 814,951, applied for December 14, 1904.—Condensers for radiotelegraphy made with sheets of metal gauze.

No. 897,278, applied for October 6, 1906.—This is one of Fessenden's specifications for improvements in methods for preventing interference. The signalling apparatus (receiver) comprises an inductive coupling and a receiver placed on the secondary circuit wholly enclosed in the primary circuit so that the primary shields it from disturbing influences.

No. 897,279, applied for December 17, 1906.—An arc method of producing undamped oscillations, the arc being contained in a vessel with gas at a high pressure.

No. 915,280, applied for February 8, 1907.—A vacuum tube receiver containing helium.

No. 916,428, applied for November 17, 1905.—An improved form of liquid barretter or electrolytic receiver.

No. 916,429, applied for July 8, 1903.—A receiver consisting of a jet of liquid.

No. 917,574, applied for March 26, 1907.—A receiver depending on the change in friction of surfaces in contact produced by electric oscillations passing through the contact.

No. 918,306, applied for July 1, 1907, and 918,307, applied for August 25, 1908. —Apparatus for producing high frequency groups of trains of electric waves. In these specifications Fessenden draws attention to the importance of employing with telephone methods of reception a group frequency in spark telegraphy which is of the order of 900 or 1000 per second. The result is to enable the ear to distinguish easily between the musical sound of the signal spark and the lower note or irregular grating sounds due to atmospheric discharges.

No. 923,962, applied for December 31, 1906.—Methods for sending and receiving simultaneously in the case of radiotelephony.

No. 923,963, applied for January 9, 1907.—Producing persistent oscillations by an electric arc formed in rare gases, Argon, Neon, etc.

The further references to some of the above mentioned specifications will be made in later chapters of this work. Fessenden has particularly devoted attention to the subject of radiotelephony, and many of his inventions, such as the high frequency alternator, have been directed to this end and are of considerable value.

Additional references to the work of Fessenden will be found in Chapters IX. and X., under the heading of Radiotelegraphic Stations and Radiotelephony.

19. Patents of Lee de Forest in connection with Wireless Telegraphy.—Another patentee who has been granted numerous patents in the United States and other countries for inventions connected with wireless telegraphy is Lee de Forest. We shall briefly abstract the subject-matter of his chief United States patent specifications, and refer to the contents of some of them elsewhere.

They cover detailed descriptions of various forms of electrolytic and magnetic wave detector, also devices proposed for affecting syntonic telegraphy, for determining the distance and location of sending stations, for various forms of aerials intended to secure immunity of a receiving circuit from influence by vagrant electric waves, and other appliances for practical working of wireless telegraph stations.

No. 716,203, applied for September 1, 1900.—This patent, granted to Lee de Forest and E. H. Smythe, is for a "variable resistance" material applicable as a wave detector, consisting of two metallic plates placed in a vessel containing a liquid. Water is stated to be "perfectly satisfactory" as the liquid, and the best results are said to be obtained when some porous material is interposed between the electrodes. The cell has its electrodes connected through two choking coils with a telephone and single voltaic cell, and, furthermore, one pole of the electrolytic cell is connected to earth and the other to an aerial. The electrodes in the cell should be close together, and may have unequal surfaces. It is stated that the action of electric oscillations on the cell is to *increase* its resistance. It is referred to in the specification as a "variable resistance conductor," altering in resistance under the action of electrical oscillations produced by electric waves falling on the aerial, but self-restoring. The sudden change in its resistance varies the current of the cell passing through the telephone, and hence creates an audible signal. The application of the arrangement as a receiver in wireless telegraphy involves the use of the Marconi aerial wire, earth connection, and choking coils. If it is a fact that the action of electric oscillations is to *increase* the resistance of such a cell, then it differs strikingly from other forms of electrolytic polarization cell, for in these last the action of electric oscillations reduces the effective resistance of the electrolyte by annulling in part or entirely the polarization of the electrodes, and so reducing the effective resistance of the cell.

No. 716,000, applied for July 5, 1901.—Contains a description of another form of variable resistance wave detector. A glass or ebonite tube has in it two plugs, one of which is capable of being advanced by a screw, so that the interspace between the two plugs can be made a small fraction of an inch. Between these electrodes is placed an electrolyte consisting of glycerine or oils, mixed with oxide of lead (litharge), and a small quantity of water or alcohol, mixed with metallic powders, preferably tin, silver, or nickel. Sometimes the ends of the plugs are made cup-shaped, and the cups filled with a mixture of oxide of lead and glycerine. This electrolytic cell is placed in series with a voltaic cell and a telephone or other telegraphic instrument, choking coils being interposed. The cell is also connected by one terminal to an aerial and the other to the earth. The operation of the battery current is to electrolyze the mixture, and form chains of metallic particles, while the action of an electric oscillation passing through the cell is to break up the chain of particles and so suddenly increase the resistance of the cell. Hence a listener at the telephone hears a sudden click of the telephone due to the decrease in the current passing through the cell, and as soon as the oscillations cease the chain of metallic particles is instantaneously reconstructed, and the resistance of the cell again falls. A train of electric waves falling on

the aerial produces, therefore, a continuous sound in the telephone, and audible singles can be made, equivalent to the dot and dash of the Morse alphabet.

No. 716,334, dated December 16, 1902.—This specification is merely a division of the previous specification applied for on July 5, 1901.

No. 720,568, applied for March 6, 1901.—This specification describes a form of duplex aerial consisting of two aerials of the Slaby type, having lateral connections at some point just above the ground. The ends of these two lateral wires are connected to the terminals of an electrolytic receiver. The length of the two lateral wires is so adjusted that the phases of potential at their open ends differs by 180 degrees.

The same specification also covers a description of a closed loop receiving aerial.

The advantage of the double aerial is stated to be that by rotating the system of antennæ round a vertical axis the variation in its sensibility enables the direction of the arriving wave front to be determined, and hence that of the radiant point.

On comparing this U.S.A. specification with that of J. S. Stone, No. 716,134, applied for January 23, 1901, it will be seen that the latter patentee had previously described a somewhat similar plan for locating the direction of the sending station by the use of double or looped aerials.

No. 730,246, applied for March 8, 1902.—This long specification, with fifty-three claims, includes a description of an application of the so-called Lecher wires as part of a receiving circuit. An aerial receiving wire is interrupted at some point near the ground and two lateral insulated wires inserted. These wires may be twisted together and contained in a box of oil. If the length of the wires is adjusted with reference to the frequency of the electric waves incident on the aerial, then stationary electric waves are set up in these wires with loops and nodes of potential at regular intervals. Any wave-detecting potential-actuated device, such as a coherer, can be placed across the two wires as a bridge at an antinode of potential, whilst any current-actuated device can be placed in the run of one of the wires at an antinode of current. The object of the arrangement is to construct a receiving aerial which will be insensitive to an aperiodic or solitary electric wave, but responsible to a train of electric waves having some definite assigned period.

No. 730,247, applied for November 4, 1902.—This is another specification covering a receiving aerial in which Lecher wires are employed, twisted together as a resonant system, sensitive only to waves of a certain definite period. A potential-actuated cymoscope is placed at the open end of the parallel wires at a potential loop, and also connected through choking coils and a single voltaic cell with a telephone as a detecting device.

No. 730,819, dated June 9, 1903.—This is a subdivision of the previous patent.

No. 749,131, dated January 5, 1904.—This is a division and a reissue of patent No. 720,568, applied for March 6, 1901, and refers to forms of antennæ intended to give direction to the radiation, and also to enable the direction of the radiant point to be determined. The radiator comprises two antennæ, one horizontal and one vertical, connected to spark balls, and the radiation is said to be concentrated in the plane of these antennæ.

No. 748,597, applied for December 24, 1902.—In this specification the patentee proposes to surround a single vertical sending aerial with a number of other aerials arranged on a parabolic line, of which the first aerial is in the focus. Each aerial may be provided with its own spark balls, the object of this arrangement being to act as a reflecting surface and direct a beam of radiation in any direction. In the absence of specific information as to performance, it is impossible to estimate the practical value of such a device.

No. 770,228, applied for December 24, 1902.—This patent is for a contact cymoscope consisting of steel and aluminium surfaces held lightly in contact with a spring. The patentee states that such an arrangement is self-decohering. It belongs to the type of microphonic receivers, which fall but slightly in resistance on the passage of an electric oscillation through the contact, and are therefore suitable for use with a telephone and local cell. If the pressure at the imperfect contact is light and properly adjusted, the cymoscope is self-restoring and requires no tapping.

No. 749,178, applied for March 5, 1903.—Contains a description of a Morse

signalling key with the contacts working under oil and under some circumstances, a magnetic blow-out being employed if necessary.

No. 750,216, applied for May 14, 1902.—This specification describes a number of arrangements of transmitting and receiving aerials for syntonic telegraphy, in which the Lecher conductors are employed as the resonant system.

No. 770,229, applied for March 14, 1902.—This specification covers arrangements for receiving aerials which are intended to be impregnable against the attacks of solitary waves or aperiodic electromagnetic disturbances, but easily influenced by periodic trains of electric waves of suitable period. Descriptions in this specification, however, do not give any sufficient proof of the actual and practical value of such arrangements.

No. 749,434, applied for June 4, 1903.—This specification contains a description of a combination of sending and receiving apparatus by which messages are to be sent and received simultaneously at the same station. A revolving commutator cuts the connection between the actual wave detector or cymoscope and the aerial at the moment when the spark happens. The patentee proposes to employ a wave detector which is not injured *per se* by strong impulses from a spark near by, such as a Rutherford magnetic detector or other self-restoring wave indicator.

No. 749,371, applied for June 4, 1903.—Comprises an application of a magnetic telegraphic wave detector, similar in principle to that of Marconi, to syntonic receiving apparatus, such that electric waves or impulses differing from those which the apparatus is designed to detect will not affect it.

His method is to construct a differential magnetic detector with two oppositely wound coils, one in connection with a simple aerial and the other in connection with an aerial with a resonant Lecher system of wires attached to it, so that it is syntonic. The idea is that irregular electromagnetic impulses will affect both aerials equally, and therefore produce no effect on the magnetic detector, whilst the syntonic trains of waves will chiefly affect one aerial alone.

No. 749,372, applied for June 4, 1903.—For a method of wireless telegraph signalling, based upon the radiation of a continuous series of high frequency electric waves having a spark frequency varied in a predetermined cycle, producing manifestations, and by means of them producing, at the receiving station, signals which vary in accordance with the variations of spark frequency.

No. 749,435, applied for June 17, 1903.—This is a specification claiming an arrangement for a wireless telegraph transmitting station, comprising a gas or oil engine, an alternator, a transformer, an extra high-tension transformer, two choking coils, condensers, an aerial wire, and earth connection. Precisely similar arrangements had been erected and employed by the Author of this treatise two or three years previously; power plant for creating electric waves involving the use of gas engines or oil engines, and high tension transformers having been in use for several years past at University College, London. Also plant erected in other places to the designs of the Author, in which gas or oil engines, alternators, high tension transformers, condensers, and oscillation transformers had for long been employed.

No. 749,436, dated June 17, 1903.—This specification covers a device in the form of a rheostat to be inserted in the circuit of the aerial at the receiving station for indicating the distance of the sending station. The practical value cannot be judged from the specification.

No. 758,517, applied for September 21, 1903.—This specification covers other devices intended to enable the distance of a sending wireless station to be determined by measuring the amount of damping or choking required to reduce by a regulated amount the signals being received. Seeing, however, that the intensity of electromagnetic waves arriving at a receiving station depends upon the state of the atmosphere as regards ionization due to sunlight and atmospheric electrical conditions, also on the surface over which the waves travel, it is doubtful if such devices have much practical value.

No. 750,180, applied for June 17, 1903.—The patentee here describes a method of starting into existence the oscillations in an electric wave producing radiator of the ordinary type, which consists in placing the spark balls at a distance just too great to permit the discharge of the induction coil or transformer to pass, and then starting the discharge of the condenser into operation by throwing upon the spark either ultraviolet light, or else discharging near them a small pilot spark, which serves the same purpose.

No. 778,818, applied for May 28, 1904.—This specification describes a form of

aerial consisting of a grid in connection with an electrolytic receiver. The grid is capable of being turned round a vertical axis into various positions, and the maximum indication is given by the receiving instrument when the screen or grid is broadside on to the direction of the waves. It is then stated that the grid will collect the largest amount of electromagnetic energy, and the patentee says that with the collecting screen 6 feet high and 15 feet wide he has been able to locate with certainty the position of a transmitting station 7 miles distant within 10 degrees of azimuth.

No. 771,819, applied for May 28, 1904.—In this specification the patentee describes apparatus intended to localize or determine the direction of the sending station. The receiving antenna is to be horizontal, and connected at one end through a wave-detecting device to the earth. This antenna is to be pivoted at the earthed end, so as to be capable of being swung round into various directions, and the response of the wave-detecting device will be greatest when the free end of the antenna points in the direction of travel of the waves. This receiving antenna is described as being short, compared with a quarter of the length of the received waves. A closed-loop receiving antenna is also described, formed of a long, narrow, rectangular circuit, of which the vertical sides are the shorter; and this is to be capable of being swung round a vertical axis into various azimuths.

No. 771,820, applied for June 8, 1904.—This specification describes the insertion of two choking coils in the circuit of an alternator, used in a transmitting station for preventing electrical oscillations from getting back into the alternator armature. The device was employed by the Author more than three years previously, and is an obvious application of the power of an inductance to resist the passage of a high frequency current.

No. 772,878, applied for June 20, 1903.—This specification describes a magnetic detector with divided iron core, similar to the one previously described by the Author in a paper to the Royal Society, entitled "A Note on a Form of Magnetic Detector for Hertzian Waves adapted for Quantitative Work." See *Proc. Roy. Soc. Lond.*, 1903, vol. 71, p. 398, sent in February 11, 1903.

No. 772,879, dated October 18, 1904.—This is a divided portion of the patent 749,434, applied for June 4, 1903.

No. 772,879, applied for June 4, 1903.—This is a specification for a method for simultaneous sending and receiving by means of suitably arranged and syntonized commutators which connect the antenna alternately to sender and receiver.

No. 802,850, applied for September 21, 1903.—This is for a method of starting the main condenser discharge by a small auxiliary or "trigger" spark.

Nos. 802,981 and 802,982, applied for December 10, 1902.—These are for an antenna of loop form which can be used as a loop or magnetic circuit antenna having small damping for receiving, but as an open circuit antenna with large radiative power for sending, and other details.

No. 806,966, applied for January 25, 1904.—Is for another form of antenna, which also acts as an open circuit radiator and as a closed circuit receiver.

No. 822,936, applied for February 2, 1906.—Covers an arrangement of antenna which is intended to be monoperiodic or to radiate only waves of one period.

No. 824,003, applied for February 20, 1906.—Another patent for arrangements of antenna circuits intended to be monoperiodic.

No. 824,637, applied for January 18, 1906.—A patent for a glow lamp oscillation detector identical in nature with the Author's oscillation valve previously described in U.S.A. Patent No. 803,684, applied for April 19, 1905.

No. 825,402, applied for December 9, 1905.—Describes arrangements intended to obviate the disturbing effects of atmospheric discharges. He makes use of the "oscillation valve" or glow lamp detector invented by the Author.

Nos. 836,070 and 836,071, applied for May 19, 1906.—These specifications describe a glow lamp detector, a replica of the Author's previously described instrument of the same kind. The patentee proposes to employ a telephone having a battery having a voltage from 25 to 110 volts in series with it.

No. 837,901, applied for February 14, 1906.—Covers an oscillation valve or glow lamp oscillation detector made with a mercury anode. The volatilization of the mercury under the action of the heated filament soon spoils the vacuum, and such an arrangement is therefore not serviceable. The inventor also states that the detector becomes more sensitive when it is placed in a magnetic field.

No. 841,386, applied for August 27, 1906.—In this specification the patentee describes a glow lamp oscillation detector, which he names an "audion," but which, like the previously described oscillation valve of the Author, consists of a

glow lamp which may have a filament of carbon or of tantalum, the bulb having sealed into it one or two metal plates on either side of the filament. The patentee's method of using the detector consists in connecting one terminal of the filament and the metal plates by a circuit external to the bulb, which circuit contains a telephone and a service of continuous electromotive force. The plates are also connected to a receiving antenna, and one terminal of the lamp filament is to "earth."

No. 841,387, applied for October 25, 1906.—A variation of the previous specification in which an "audion" with two separate internal metal plates is employed, one of these being connected by an external circuit containing a telephone and voltaic battery with one terminal of the lamp, and the other plate by a circuit to the other terminal of the filament, this last circuit having induced in it oscillations by those created in the receiving antenna.

No. 879,532, applied for January 29, 1907.—This covers the description of an "audion" or glow lamp detector, having one plate and a metal grid in the bulb, the connections being as described in the previous specification.

No. 913,718, applied for June 25, 1907.—This specification describes a device consisting of a rotating commutator for cutting up persistent or undamped oscillations created in an antenna into equi-spaced groups of equal duration, the object being to provide a method of syntonization in which the turning is effected for the group frequency and not the oscillation frequency.

20. Patents of John Stone Stone for Electric Wave Wireless Telegraphy.—The United States patents for electric wave telegraphy granted to J. S. Stone, together with their equivalents in other countries, form a very voluminous contribution to the patent literature of the subject. Nearly one hundred United States patents have been granted to this patentee alone. In many cases these specifications are learned contributions to the literature of the subject, filled with valuable references to other sources of information.

A complete analysis of Stone's specifications would occupy too much space. Broadly speaking, they may be divided into four classes—

(i.) Those concerned with proposed methods for the achievement of syntonic telegraphy, or the isolation of receiving stations or protection of receivers from the action of vagrant waves.

(ii.) Those describing forms of wave detector or cymoscope.

(iii.) Those covering the construction of various forms of transmitting and receiving circuit, and the production of continuous trains of waves.

(iv.) Miscellaneous specifications covering devices proposed for localizing the direction of the arriving waves and other matters.

We shall briefly refer to the contents of his chief specifications:—

No. 714,756, applied for February 8, 1900; also No. 714,831, a divided portion of the above, applied for January 23, 1901.

The patentee describes in these specifications the inductive coupling of an aerial and closed oscillation circuit by the use of an oscillation transformer, and in some cases he interposes one or more closed oscillation circuits between the aerial and the spark circuit or final receiving circuit. Stone was evidently well aware at the date of his application that in the case of inductively coupled circuits, oscillations of two periods are created in the secondary circuit, which differ in period from each other, and from the free or natural time period of the circuit taken alone.

Taking the transmitting circuit first, the patentee states that his object is to create in the aerial forced oscillations of a single frequency,

which may with advantage be the natural frequency of the aerial. This he suggests may be done by coupling the aerial inductively with another closed oscillation circuit containing an adjustable inductance, and then again coupling this last closed circuit with another in which there is a spark gap, so that oscillations are generated in the last circuit by the discharge of a condenser. There are no numerical instances in the specification, and it is not at all clear from it how the user is to proceed to adjust the inductances and capacities of the circuits so as to secure the desired result. In the same manner the receiving circuit is to consist of a number of inductively connected circuits in resonance with each other, the object of which is to facilitate the transmission to the cymoscope of oscillations having that definite period, but to prevent stray or vagrant waves of other period from affecting it.

No. 12,149 is a reissue of the above specification (No. 714,831), dated August 25, 1903. Application for reissue filed July 22, 1903.

The two above-mentioned specifications should be read in connection with the following United States patents of Stone, which are closely connected with them :—

No. 714,832, applied for January 23, 1901.
No. 12,151, a reissue of the above, dated September 8, 1903.
No. 714,833, applied for January 23, 1901.
No. 12,152, a reissue of the preceding patent, dated September 8, 1903.
No. 714,834, applied for August 8, 1902.
No. 12,141, a reissue of the preceding patent, dated August 4, 1903.
No. 767,975, applied for November 24, 1903.
No. 767,976, applied for November 24, 1903.
No. 767,984, applied for November 25, 1903.
No. 767,989, applied for December 19, 1903.
No. 767,990, applied for December 19, 1903.

The two last are a divided application of the patent No. 767,984, of November 25, 1903.

All these specifications cover in various ways the inductive coupling of an aerial with the nearly closed oscillation-producing circuit which contains a spark gap. The invention which they purport to protect is the production of oscillations in an aerial earthed at the lower end and insulated at the upper end in such fashion that "forced oscillations of a single period" are created in this aerial. Stone proposes to do this, in the first place, by inserting in the nearly closed oscillations circuit containing the spark gap a large inductance, so as to swamp the effect of the mutual inductance of the two circuits in generating oscillations of two different frequencies in the secondary circuit. We have already explained that if L and N are the two separate inductances of two circuits inductively connected together with a coefficient of mutual inductance, M, then the reaction between the circuits depends on the coefficient of coupling $\frac{M}{\sqrt{LN}}$. Hence we can make this quantity small either by decreasing M or by increasing L.

The object the patentee has in view is the radiation of waves of one single frequency of simple harmonic form, and his proposed means of achieving this consists in reducing the reaction of the open circuit on the closed energy-storing oscillation circuit by making the

inductive coupling "loose," or else by inserting inductance in the closed circuit and producing a forced oscillation in the aerial, which has a period dependent on the constant of the closed circuit, but not those of the aerial itself.

In the specification (U.S.A.) No. 767,975, of November 24, 1903, Stone explains at some length wherein he thinks his mode of inductive coupling differs from that of Marconi, as described in the latter's British patent, No. 7777, of April 26, 1900.

No. 767,979, applied for November 24, 1903.—This is for the production of "forced oscillations" in an aerial consisting of a plurality of wires.

It is difficult to understand how it is that the United States Patent Office grants patents (popularly supposed to be after careful search for anticipations) for such obvious combinations of ancient elements. At the date of this specification Marconi had employed multiple aerials of various forms for several years, and the production of forced oscillations in them is an obvious application of existing knowledge.

In the next place we come to four specifications :—

No. 767,986, applied for November 25, 1903.

No. 767,988, applied for December 8, 1903.

No. 767,998, applied for February 15, 1904.

No. 767,999, applied for February 15, 1904.

The last three being divided applications of the first named.

These specifications include numerous claims for employing large elevated horizontal plates as antennæ. Having regard to the fact that Marconi, in his first British patent specification, in 1896, had described the use of elevated plates, or cylinders, and insulated conductors, generally used as aerials or radiators in electric wave telegraphy, it is difficult to see that any novelty can be considered to attach to the claims for these arrangements in the specifications numbered above.

No. 767,983, applied for November 25, 1903.—This specification covers a method proposed for producing continuous trains of electric waves. It appears to consist in the use of a battery of high resistance, associated with a spark gap and inductively coupled to an aerial.

No. 767,993, dated August 16, 1904.—Is a divided application of the above specification.

No. 716,134, applied for January 23, 1901; No. 12,148, a reissued patent corresponding to No. 716,134, dated August 18, 1903; No. 716,135, applied for January 23, 1901.—These three specifications disclose a method for locating the direction of the sending station or source of the electric waves which consists in employing at the receiving station two aerials placed at one half of a wave length apart. These are capable of being rotated in azimuth and are connected to one receiver, so that if oscillations are created in the aerials, differing in phase by 180 degrees, the cymoscope is not affected. This device may look well on paper, but the weak point in it is that it could not be effective with solitary or aperiodic waves nor with short highly damped trains of waves.

It is based on the assumption that equal and opposite oscillations can be generated at the same time in the two aerials, and also upon the use of a relatively short wave. It could hardly be employed with waves having a length of 1000 feet or more. It presupposes the use of very long slightly damped trains of electric waves of wave lengths not exceeding 200 or 300 feet.

Nos. 717,511, 717,512, application of January 23, 1901.—These two specifications cover the description of a proposed method for increasing the time period of oscillation of an aerial by clothing it with a dielectric sheath which may have embedded in it ferromagnetic material in a state of powder. Unless the dielectric sheath was enormously thick it would not have much effect, and the magnetic hysteresis of the ferromagnetic powder would probably assist in greatly damping the oscillations. Very much the same idea was subsequently placed in other patent specifications by R. A. Fessenden.

No. 768,000, applied for February 23, 1904.—This covers a form of multiple spark ball discharger placed in a box in which air or other gases may be compressed.

No. 768,004, applied for April 11, 1904.—This specification describes numerous

forms of aerial in which the spark gap is short-circuited either by a condenser or by a condenser in series with inductance. The patentee gives a useful and extensive series of references to the literature of the subject, and states that the first use of a condenser shunting a spark gap was due to Blondlot.

We then reach a group of specifications by Stone which are chiefly concerned with thermal and electrolytic receivers, the thermal receivers being in some cases bolometer detectors; that is, dependent on the heating effect of an electric oscillation on a very fine wire, and in other cases on the use of thermoelectric couples.

These specifications of Stone are full of useful references to original papers on the bolometer and kindred subjects, and are, in fact, a learned exposition of the whole subject.

The principal specifications are as follows:—

No. 767,971, applied for August 11, 1902.—This deals with the construction of a bolometer detector made with fine wire. The patentee describes the advantages of bismuth wire in place of iron or platinum. He gives copious references to the literature of the bolometer and to the form of oscillation bolometer used by Rubens and Ritter (which he adopts) and others. The arrangements are, in fact, the combination of a Rubens and Ritter bolometer with an aerial receiver and earth connection.

No. 767,972, applied for September 10, 1902.—This is a divided application of the patent No. 767,971.

No. 767,980, applied for November 5, 1903.—This specification also contains very useful notes on the bolometer, but is principally concerned with the application of a bolometer detector to a duplex receiving aerial, so arranged that by rotation in different azimuths the direction of the arriving waves may be determined, these aerials being separated by a distance equal to half a wave length (see also Stone's U.S.A. specification, No. 716,134).

No. 767,981, applied for November 25, 1903.—Deals with a special form of bolometer cymoscope consisting of a very thin strip of gold leaf, which is cast into paraffin and cut to the required small size by a microtome. The rise in temperature produced when electric oscillations pass through it is to be detected by its change in resistance. In this specification very useful references are given to Wollaston's original paper containing the account of his method of making ultra-fine platinum wire, and to other books where the process is described.

No. 767,992, applied for January 15, 1904.—This is a divided application of the above patent, No. 767,981.

No. 767,985, applied for November 25, 1903.—This contains a description of a mode of manufacturing a thermoelectric pile of platinum and gold for use as an oscillation detector.

No. 767,987, applied for December 8, 1903.—This is a divided application of the foregoing patent, No. 767,985, for a thermoelectric receiver.

Nos. 767,996 and 767,997, applied for February 15, 1904.—These two specifications cover a form of thermal receiver. It consists of a fine Wollaston platinum silver wire with platinum core and silver exterior, which just dips into mercury. The mercury dissolves away the silver and leaves a short length of platinum exposed, and since mercury does not wet platinum, the patentee says that a short length of the platinum would be exposed above the mercury, on account of the capillary depression of the mercury. Its action would, however, depend entirely upon the platinum wire not being amalgamated, and it may be doubted whether the removal of the silver by the mercury could be effected completely without amalgamating the platinum wire as a result.

No. 768,003, applied for April 11, 1904.—In this specification Stone redescribes the electrolytic detector consisting of a fine Wollaston platinum wire just dipping

into nitric acid. He states that the cell is inoperative unless the fine platinum wire is made the anode. This, however, was well known prior to the date of this specification. Stone appears to agree with the opinion of Fessenden that the action of the cell is in part at least thermal, the change in resistance being due to the heating of the electrolyte under the action of the oscillations.

We then come to a group of Stone's specifications which have reference to securing the privacy of communication by electromagnetic waves. The object of these arrangements is to render a particular station receptive for waves only of one frequency, but not receptive for waves of other frequency, or of aperiodic or isolation waves.

It is impossible to say by simply reading the above specifications whether they describe real inventions which have been practically tried and found to be successful, or whether they represent simply anticipatory opinions. In the absence of definite information on this point, it is not necessary to analyze these specifications very closely.

Four specifications of considerable interest—viz. No. 716,135, applied for January 23, 1901; No. 767,970, applied for January 23, 1901; and No. 768,002, a divided application referring to an original applied for on November 25, 1902, and No. 899,272, applied for August 17, 1906—refer to a method for localizing the direction of a sending station, or rendering a receiving station receptive only to waves coming from a certain direction. They are based on the fact that if two aerials are set up at a distance equal to half a wave length they will be affected in a similar manner by a train of waves meeting them broadside on, but will have produced in them oscillations in opposite phase if subjected to the action of a wave train travelling in the direction in the plane of the aerials.

These antennæ are connected to a receiving circuit in such manner that equal oscillations in the two antennæ neutralize each other's effect, but if the oscillations are not of equal amplitude or are opposed in phase they do actuate the receiving mechanism. The chief objection which can be urged against this plan is the great length of wave now used in radiotelegraphy, which necessitates a considerable interval between the antennæ.

Three specifications—No. 725,634, applied for January 3, 1903; No. 725,635, applied for March 12, 1903; and No. 725,636, applied for March 12, 1903—also refer to complicated arrangements intended to isolate wireless telegraph stations. The signals are for the most part transmitted by means of punched paper tape, but for the elaborate arrangements suggested the reader must be referred to the original specifications.

Five other specifications—No. 767,978, applied for November 24, 1903; No. 767,991, applied for December 23, 1903 (a divided application of the previous one); No. 767,932, applied for November 25, 1903; No. 767,994, applied for February 13, 1904; No. 767,995, applied for February 13, 1903—all describe elaborate arrangements, having as their object the isolation of wireless telegraph stations, and the remarks made with reference to the previous group of specifications apply to these also.

No. 768,001, applied for February 23, 1904.—This specification describes a system for selectively receiving signals transmitted by waves of predetermined electrical frequency and predetermined group or wave-train frequency.

Several specifications have been filed by Stone, the objects of which are to describe arrangements intended to permit transmission and reception to be effected simultaneously at one station; that is to say, to provide a means by which the waves sent off from one aerial shall not affect or prevent the reception

of other messages from a distant station at closely adjacent aerials. Two such specifications are—

Nos. 716,136 and 716,177, applied for January 23, 1901.—The arrangement proposed is a single receiving aerial set between two transmitting aerials so arranged that these two transmitting aerials are traversed by electric oscillations in opposite directions, and therefore nullify each other's effect upon the adjacent receiving aerial. If, however, these transmitting aerials are placed at a distance equal to one wave length apart, each being half a wave length distant from the single receiving aerial midway between them, their effects will be combined together at any distant point lying in the plane of the two transmitting aerials. The patentee, however, treats the subject as if wave trains were continuous and suffered no decrement.

Other kindred specifications are—

Nos. 717,509, 717,513, 717,514, 717,516, applied for January 23, 1901.—All describe arrangements by which it is proposed to relay wireless telegraph messages, so that signals received on an aerial may set in operation apparatus which retransmits the messages from another adjacent transmitting aerial.

The practical problem here involved is one which has been attacked by numerous inventors, particularly E. Guarini, and some have claimed that they have given a solution of it, but the author is not aware that any of the proposed solutions suggested have reached the stage of practical verification.

No. 767,973, applied for October 30, 1903.—This specification is an interesting treatise on the subject of the propagation of electric waves from an earthed aerial. The advantages of a good earth are pointed out, and a number of interesting diagrams are given in the specification. The particular purpose of the specification appears to be an insistence on the advantages of a good earth connection, already at the date of the specification a well-known fact and the reasons for it understood.

No. 767,977, applied for November 24, 1903.—Deals with the advantages of quartz glass as a dielectric for high-tension condensers, and with the advantages of a core composed of a paramagnetic substance for oscillation transformers.

No. 768,005 describes a tower or mast for supporting an aerial wire, the said tower being cut up into insulated sections, and the mast supported by stays in the same way, divided into sections by insulators. This last method of supporting a mast, as used for a wireless telegraph aerial, had been in public use by Marconi for some years before the date of this specification of Stone.

For information on other and later radiotelegraphic patents of Stone, lists of United States Patents must be consulted.

21. The Work of other United States Patentees and Inventors in Radiotelegraphy.—Another extremely industrious patentee in the United States is H. Shoemaker, who is accountable for more than forty patents on the subject between 1901 and 1905. His specifications comprise mechanical devices for conducting multiplex radiotelegraphy, improvements in coherers, various wave detectors, and sundry devices for improving the transmitter. None of them are, however, of sufficient importance to make it worth while to abstract them seriatim. The most useful contributions which have been made to the subject by United States inventors have been in the direction of improved forms of detectors. General Dunwoody of the United States Army discovered in 1906, that a crystal of carborundum (carbide of silicon) possessed a unilateral conductivity for electric oscillations, and could therefore rectify them and serve as a detector of electric wave trains when associated with a telephone as explained in Chap. VI. (see United States specification of H. H. C. Dunwoody, No. 837,616, applied for March 23, 1906). This was followed by the discovery by Professor G. W. Pierce of similar properties in several other crystals, and of a peculiar property

of rectifying oscillations possessed by the contact between certain substances such as molybdenite and a copper point pressed against it. Pierce discovered the rectifying power of hessite (a native telluride of silver), octahedute and brookite, and anatase (a native oxide of titanium), and also of hematite and coovellite. It had long previously been known that psylomelan possessed a marked asymmetric conductivity (see U.S.A. patents of G. W. Pierce (No. 879,061, 879,062, 879,117 and 923,700). Also several such asymmetric conductors composed of two substances, such as a brass point and a solid oxide of zinc surface, were discovered by G. W. Pickard (see U.S.A. patent No. 924,827). The details of some of these detectors have been discussed in Chap. VI. in giving descriptions of various wave detectors. These rectifying detectors used in conjunction with a telephone are simple, inexpensive and easily adjusted, and hence have found extensive use.

22. Radiotelegraphic Inventions in France, Italy, and other Countries.—In addition to the pioneer work of M. E. Branly, the inventor of the metallic filings cymoscope, valuable scientific work has been done in France by MM. A. Blondel, C. Tissot, P. Janet, H. Poincaré, J. Ferrie, and A. Turpain. M. Tissot's work has been chiefly in connection with quantitative measurements, and a valuable *résumé* of these is found in his book, "Sur le Résonance des Systèmes d'Antennes," published in 1905. He employed the bolometer bridge as his instrument of research, and contributed much to the quantitative study of radiotelegraphy. The scientific writings of Professor A. Blondel and of Professor H. Poincaré have been most valuable in elucidating the subject.

In Italy MM. Bellini and Tosi have contributed work of much utility in connection with directive radiotelegraphy, which is considered in detail in Chap. VIII.

Apart from the problem of generating and radiating prolonged trains of waves and controlling them for signalling purposes, and detecting them by the simplest means, the attention of inventors has been largely directed to the problem of increasing the privacy of communication.

We have already indicated the method based on syntony between the oscillation periods of the sending and receiving apparatus, but many other methods have been tried.

Inventors have endeavoured to solve this problem by devising methods in which the syntonism between the stations is not that of the frequencies of the waves, but the much lower frequency of the wave trains. Thus a series of groups of waves may be sent out from a transmitting station, each wave train consisting, say, of 200 waves, having a frequency of 1,000,000. Then the whole wave train would occupy only one five-thousandth of a second. The wave trains might follow each other with a frequency of 100. Then 100 trains of waves would pass any point per second, and the so-called group frequency would be only one-fiftieth part of the wave frequency. It is then possible to construct receiving apparatus which shall be sensitive only to the group frequency.

The original suggestion for this method of working came from M. A. Blondel, who, on August 6, 1898, deposited with the Academy

of Sciences in Paris a sealed envelope containing a description of his improvements in syntonic wireless telegraphy which was opened on May 19, 1900.[48]

From the transmitter trains of electric waves are sent out at definite intervals controlled by a regular interrupter. At the receiving end a single voltaic cell keeps a condenser charged until a cymoscope of the metallic filings type is rendered conductive by the oscillations created in the receiving aerial by the waves falling on it. Under these circumstances the condenser discharges through a telephone. The telephone used, however, is one of the Mercadier monotone telephones, or some equivalent form which does not respond to a single current or discharge through it, but only to a regulated series of currents at certain intervals, say 100 per second. Hence, if the wave trains continue to arrive at these intervals they will create a sound in the telephone, and this may be shorter or longer to correspond with a Morse dot or dash, according as the key at the transmitting end is manipulated. The receiver will, therefore, be insensitive to irregular or aperiodic impulses, but sensitive to wave trains, or even solitary waves, arriving at the determined rate fixed by the timing of the monotone telephone.

That this may be achieved the sparks or trains of oscillations in the transmitter must be separated by exactly equal intervals of time, and when induction coils or even transformers are used this is very far from being the case.

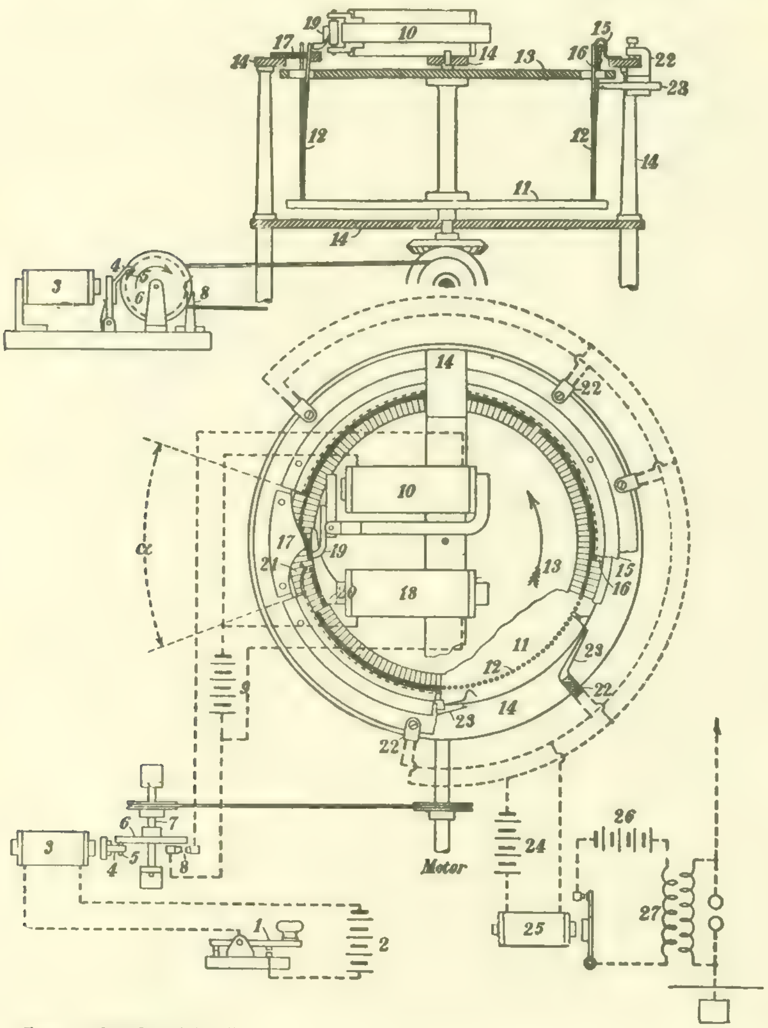
Hence these methods, though they look well on paper, have never been reduced to successful practice.

We may then pass on to notice briefly the attempts that have been made to secure isolation by a plan which is not dependent on electrical syntony. One of these is that due to Anders Bull.[49] In the first arrangements proposed by this inventor, a receiver is constructed which is not capable of being acted upon merely by a single wave or train of waves, or even a regularly spaced train of electric waves, but only by a group of wave trains which are separated from one another by certain unequal predetermined intervals of time. Thus, for instance, to take a simple instance, the transmitting arrangements are so devised as to send out groups of electric waves, these wave trains following one another at time intervals which may be represented by the numbers 1, 3, and 5; that is to say, the interval which elapses between the second and third is three times that between the first and second, and the interval between the third and fourth is five times that between the first and second. That is achieved by making four electric oscillatory sparks with a transmitter of the ordinary kind, the intervals between which are settled by the intervals between holes punched upon strips of paper, like that used in a Wheatstone automatic telegraphic instrument. It will easily be understood that by a device of this kind groups of sparks can be made, say four sparks rapidly succeeding each other, but not at equal intervals of time. One such group constitutes the Morse dot, and two or three such

[48] See *Comptes Rendus*, May 21, 1900, vol. 130, p. 1383, "Sur la Syntonie dans la Télegraphie sans fil;" or, "Rapports du Congrés International d'Electricité," p. 341. Paris, 1900.

[49] See *The Electrician*, February 8, 1901, vol. 46, p. 573.

groups succeeding one another very quickly constitute the Morse dash. These waves, on arriving at the receiving station, are caused to actuate a punching arrangement by the intermediation of a coherer or other cymoscope, and to punch upon a uniformly moving strip of paper holes which are at intervals of time corresponding to the intervals between the sparks at the transmitting stations. This strip



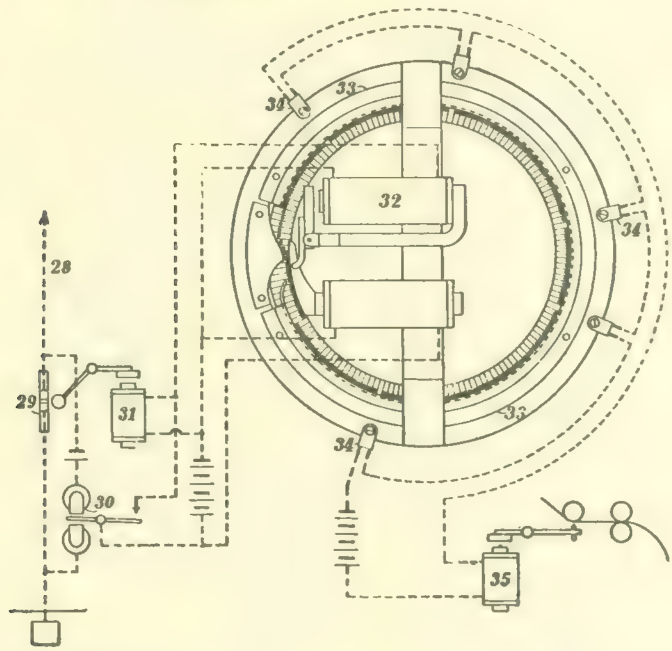
From "The Electrician."

FIG. 72.—Diagram of Connections in the Anders Bull Transmitter for Electric Wave Telegraphy.

of paper then passes through another telegraphic instrument, which is so constructed that it prints upon another strip a dot or a dash, according to the disposition of the holes on the first strip. Accordingly, taken as a whole, the receiving arrangement is not capable of being influenced so as to print a telegraphic sign, except by the operation of a series of wave trains succeeding one another at certain assigned unequal intervals of time.

To carry out these principles in practice, two instruments have to be employed. At the transmitting end one to effect the conversion of Morse signals, made with an ordinary key with the properly spaced series of wave trains radiated from the aerial. This is called the disperser. At the receiving station another instrument called the collector is employed to effect the reconversion of the wave groups into the Morse signal printed on a Morse inker. The arrangements are shown in the diagrams in Figs. 72, 73, 74, and 75, taken, by permission, from an article by M. Anders Bull in *The Electrician*.[50]

If a dot in the Morse code is to be transferred from a station, A, to another station, B, a series of, say, five wave impulses at intervals a', b', c', and d' is despatched. The receiver at B, tuned for these



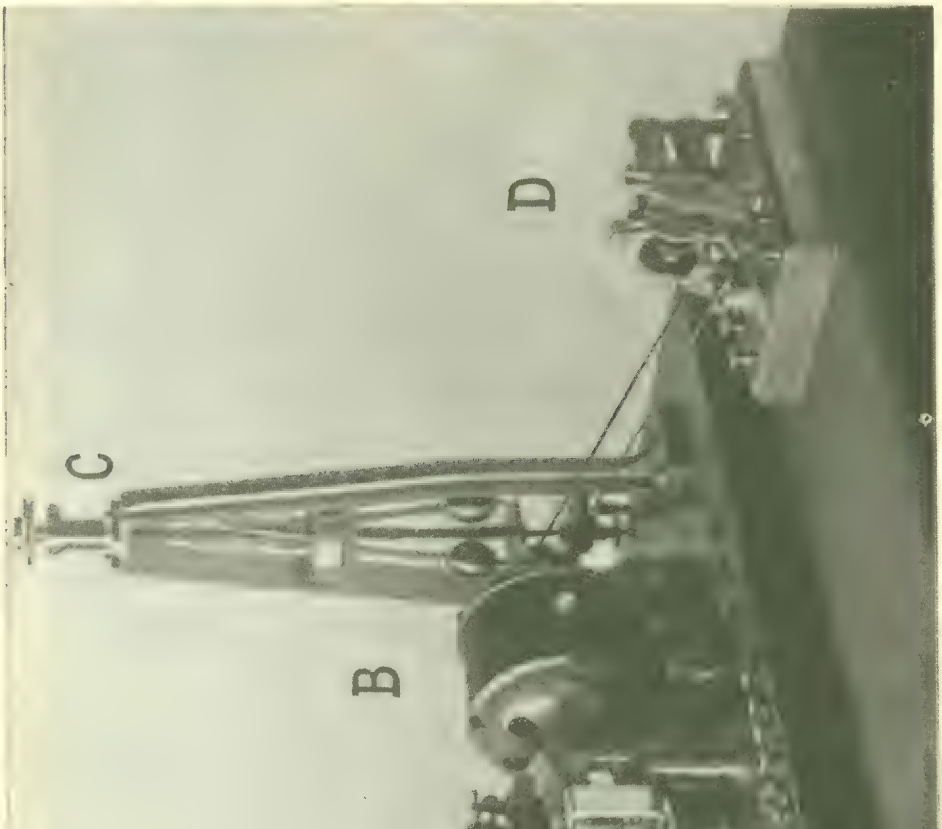
From "The Electrician."

FIG. 73.—Diagram of Connections in the Anders Bull Receiver for Electric Wave Telegraphy.

intervals, collects the five impulses and registers them as a dot on the tape of a Morse apparatus ; in transmitting a dash, a sequence of such series is despatched from A, and the receiver at B will register a row of closely placed dots (a dash) on the tape. If A wants to communicate with another station, C, a second series is used, the intervals being a'', b'', c'', and d''. These series will not be recognized by the receiver at B, as the intervals do not correspond with the adjustment of the latter. The receiver at C will, however, receive and record the signal. In this way, by using series of different forms, one can telegraph selectively from a transmitting station to any number of receivers.

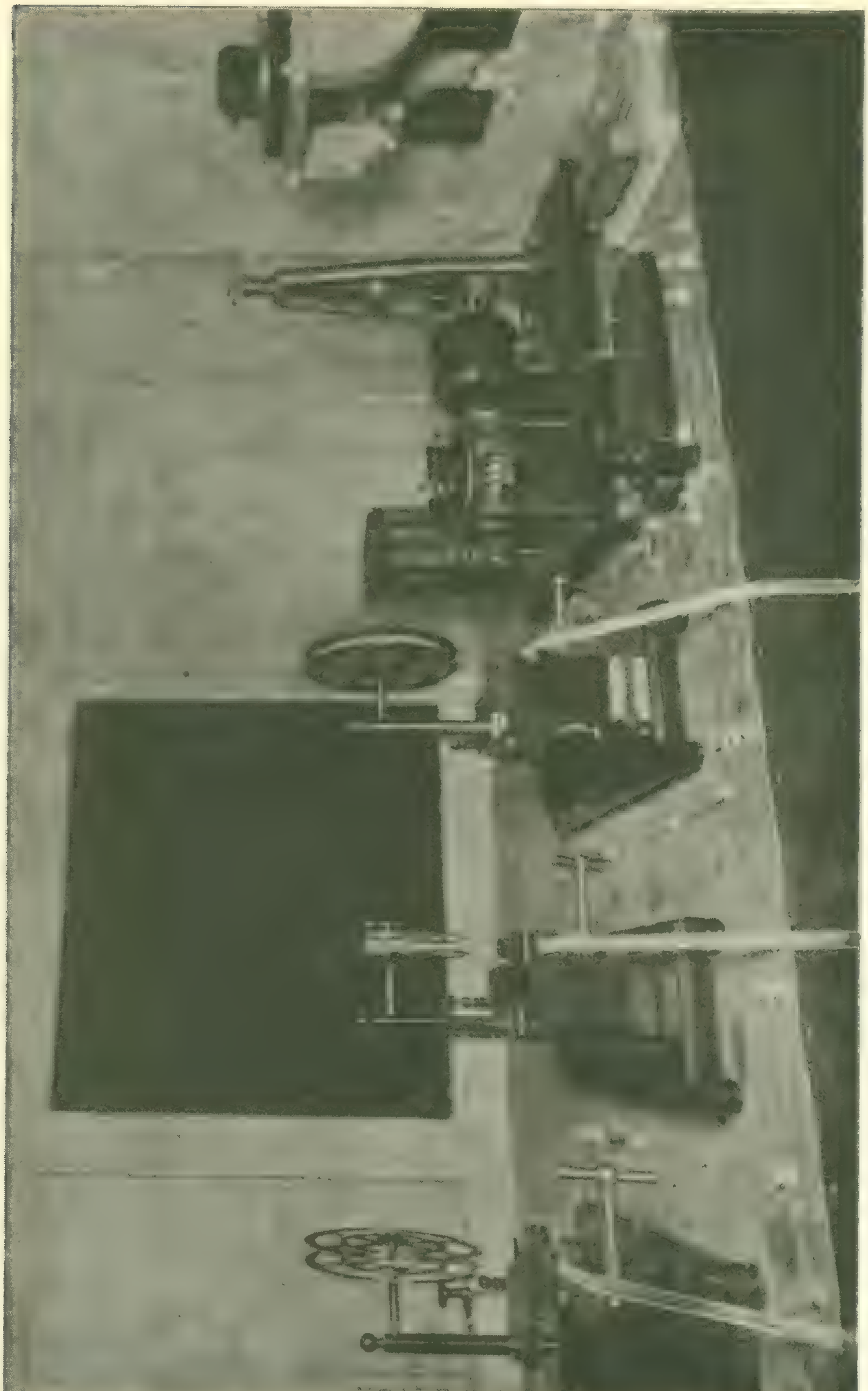
The conversion of the Morse signs into series at the transmitting

[50] See *The Electrician*, January 2, 1903, vol. 50, p. 418.



From "The Electrician."

FIG. 74.—View of Transmitting Apparatus used in Anders Bull System of Selective Wireless Telegraphy.



From "The Electrician."

Fig. 75.—View of Receiving Station, showing Three Independent Receivers in Anders Bull System of Selective Wireless Telegraphy.

station, as well as the reconversion of the series into dots at the receiving station, is accomplished automatically by two instruments, the disperser and the collector, respectively. Sending is carried out in the usual way by pressing down a Morse key for short or long periods.

Fig. 72 shows diagrammatically the connections at the transmitting station. By pressing the key 1, a current will flow from the battery 2 through the windings of the electromagnet 3, the armature of which is fitted with a hook, 4, to grasp the stop 5 on the disc 6. The latter is loose on the pivot 7, which rotates with a velocity of about five revolutions per second, the friction being sufficient, however, to confer on the disc a tendency to rotate with the pivot. When, therefore, the armature is attracted, the disc 6 is released and starts rotating; the stop 5, in passing the contact springs 8, will close a circuit, including the battery 9, and the electromagnet 10, mounted on the frame of the disperser. If the key is pressed only for a short time (in order to send a dot), the hook, having released the disc, resumes its normal position, and the disc is stopped after one revolution. Only one impulse is then sent through the windings of the magnet 10. If, however, the key is pressed long enough to allow the disc to make several revolutions, a number of impulses at regular intervals of one-fifth of a second are sent round the magnet.

The disperser consists of a disc, 11, to which is fixed a large number of concentrically arranged vertical steel springs, 12. The upper ends of the springs are free, and are passed through radial slots in a second disc, 13; their ends are thus allowed freedom in a radial direction only. The two discs are mounted on the same spindle, and revolve within the frame 14, to which is fixed a ring, 15, serving as a guide for the points, so that during a revolution they are caused to glide either within the ring or in the ∩-shaped groove, 16, formed by the latter. A piece of the ring corresponding to the angle *a* (Fig. 72) is cut off, and in its place is fitted a piece of bronze, 17, which bends the ends of the springs towards the pole of the magnet 18. This magnet is constantly excited by current from the battery 9, and the steel springs are attracted by it. Their elasticity being overcome by the strength of the magnet, and the bronze finger 19 being in its normal position, the springs will slide along the pole of the magnet 18, and will not be released until they have reached the edge 20. On further revolving, they will glide within the ring 15. If, on the contrary, the magnet 10 is excited, the finger 19, fixed to the armature, will be pushed over the pole of the magnet 18, and protrude slightly in front of it. Then when the springs pass by this finger, they will be forced from the pole of the magnet 18, and on account of their elasticity will resume their vertical position. They will, therefore, enter the ∩-shaped groove at 21, and remain in the latter for one complete revolution.

Around the circumference of the disperser a number of contact devices, 22, are fitted, consisting of two contact springs, 23, insulated from each other; by the aid of screws these devices may be fastened around the frame at any desired angular intervals. The contact springs are arranged in such a way as to allow the steel springs moving within the ring 15 to just clear them, while the steel springs

in the groove 16 protrude, and therefore in passing, will establish contact. When the disperser is working, provided the magnet 10 has not been excited, all the steel springs will glide within the ring 15, and consequently all the contact devices 22 will be open. If, however, a short current impulse is sent through the windings of the magnet 10, a steel spring is brought into the groove 16, and establishes contact successively at every one of the contact devices. The contact springs are electrically connected, as shown in Fig. 72, and, accordingly, each time a contact is made, current from the battery 24 will excite the interrupter magnet 25, the armature of which will be attracted, causing a current from the battery 26 to flow through the induction coil 27. On the subsequent opening of the circuit, a spark discharge takes place between the secondary terminals of the coil, and a wave impulse emanates from the transmitting station. Consequently, for each current impulse that is sent through the windings of the disperser's magnet 10, a number of wave impulses corresponding to the number of the contact devices 22 are despatched. The discs revolving at approximately constant speed, the time intervals between the impulses of such a series will be proportional to the angular distances between the contact devices, and by putting these in different positions around the frame of the disperser, one can vary the form of the despatched series at will.

At the receiving station the wave impulses strike the mast wire 28 (Fig. 73), lowering the resistance of the coherer 29, and causing the relay 30 to become excited. The latter closes the circuit for the tapper 31, by which the initial resistance of the coherer is restored, and at the same time a current impulse is sent through the windings of the collector magnet 32, which is shunted with the tapper. As the collector is constructed in the same way as the disperser, a steel spring for each arriving wave impulse is brought into the groove of the ring 33. The disc to which the steel springs are fastened, like that of the disperser, revolves at approximately isochronous speed, and consequently the angular distances between the springs brought into the groove will be proportional to the intervals of time between the impulses that have impinged upon the mast wire 28. A series of, say, five impulses will, therefore, cause five springs to be brought into the groove at angular intervals corresponding to the intervals of time between the impulses. Around the frame of the collector are fitted the same number of contact devices, 34, as are on the disperser, and, similarly, only the springs moving in the groove will be able to establish contact. The contact devices of the collector are, however, connected in series (Fig. 73), so that a current cannot flow through the Morse apparatus 35 until contact is established simultaneously at all the points. If now these points are adjusted to the same mutual angular distances as the steel springs, which, on the arrival of a certain series of impulses, are brought into the groove, then such a group of steel springs will, during the revolution of the disc, cause a momentary simultaneous contact at all the points; a current impulse then flows through the Morse apparatus, and is registered as a dot on the tape. Consequently, a continuous succession of series, despatched by the transmitter when a dash is to be transferred, is registered as a continuous row of dots. Series of any other form

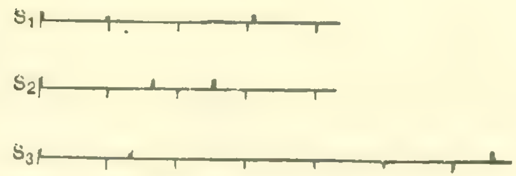


FIG. 76.—Signal Forms used in Anders Bull System of Selective and Independent Wireless Telegraphy.

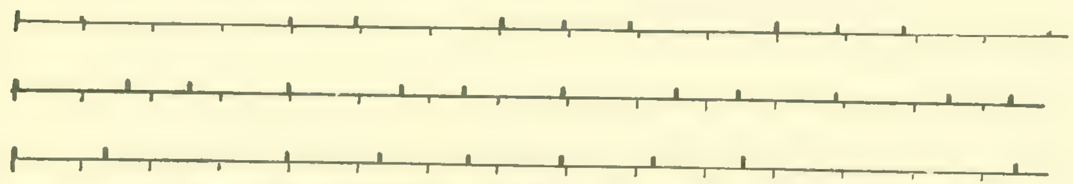


FIG. 77.—Signal Codes in Anders Bull System of Selective Wireless Telegraphy.

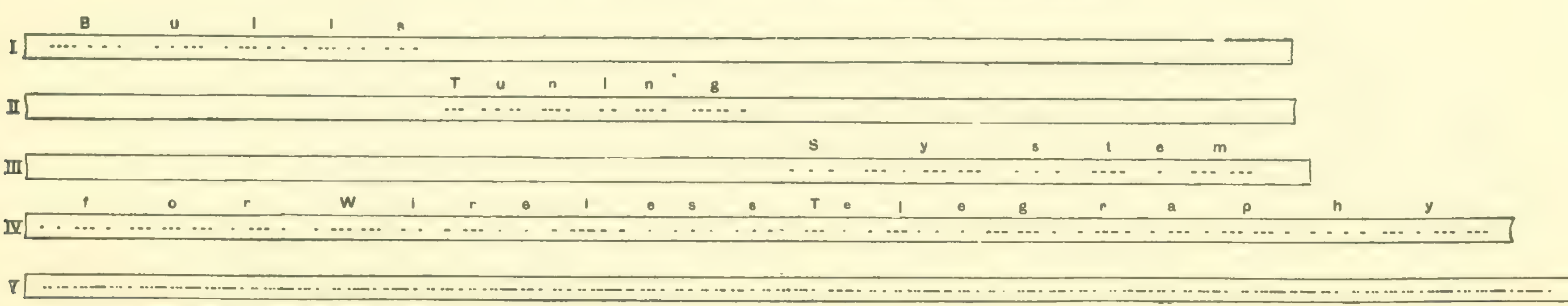


FIG. 78.—Reproduction of Morse Tapes, showing Independent Messages received simultaneously by the Anders Bull Apparatus for Selective Wireless Telegraphy.

[*To face p.* 627.

than the one to which the collector is adjusted cannot cause a simultaneous contact of the devices 34, and therefore they will not be registered by the Morse apparatus.

Fig. 74 shows the instruments used in the experiments. The disperser and collector are here combined in one apparatus, A, one half serving for despatching and the other for receiving messages. The apparatus is geared to a small motor, B, the speed of which is regulated by a brake regulator of the Siemens and Halske type, C. The disc carrying the steel springs is rotated at a speed of about one revolution per second, and the number of the springs is 400. D is the automatic device above indicated by 3–8 in Fig. 72, and is worked from the shaft of the motor. E is a relay, designed for rapid acting, the armature being very slight and the iron core laminated. It works well with 0·1 of a milliampere.

At the time of writing the above description, the inventor had only been able to mount one transmitting and one receiving station, but he had provided the disperser with three sets of contact devices 34, any one of which could be put in connection with the interrupter of the induction coil by means of a switch. The same key could be used to despatch series of three different forms, and at the receiving station the collector was provided with three sets of contact devices, each of which was connected to a Morse apparatus; these being adjusted in such a way as to correspond with the three forms of series to be despatched from the transmitting station. Fig. 75 shows the complete receiving station, with three independent Morse printers.

The number of impulses in each series is only three, and S_1, S_2, and S_3 in Fig. 76, show diagrammatically the three forms used. Time is represented by the length of the horizontal line, and the impulses by heavy cross strokes. The distance between two of the fine cross strokes represents 0·05 of a second. In Fig. 77 is shown how the series succeed each other when the key is pressed for a long time. By aid of these three series it was possible to telegraph selectively to any of the three Morse machines at the receiving station. The messages arrived very distinct and precise, and appeared exclusively on the tape of the machine for which they were intended. I. to III. in Fig. 78 shows three pieces of tape simultaneously unwound from the three Morse machines, when words were sent by the transmitter, in each of the three series S_1, S_2, and S_3 successively. The tapes show that when one machine was working no signal was registered by either of the other two.

As far as the author knows, this is the greatest number of receivers that, up to the present, have been worked selectively by wireless telegraphy; but it is evident, however, that they may be increased by varying the forms of the series. The different transmitters and receivers will work equally well if mounted at different stations, and it is quite immaterial whether the distance to be covered is great or short; in these respects the present system possesses an advantage over those based on electric syntony. The working distance over which these experiments were carried out was only about 100 yards, the energy of the transmitter being small in proportion. Several despatches can be simultaneously transmitted by this system

without interference; but, unfortunately, the inventor was unable to experiment in this direction owing to the lack of apparatus at his disposal.

It might be thought that the speed of working must be very limited, a dot requiring a series of at least three impulses; but this objection is justified only to a certain extent, as the dashes hardly require more impulses than by other systems. The dashes may, without fear of confusion, consist of only two dots, and two series are therefore sufficient, making six impulses a minimum for the transference of a dash. Although no arrangements for great speed were made in these experiments, fifty letters a minute were easily transmitted, and this speed could be considerably increased. The system may also be, with little difficulty, adapted to the Hughes type-printing apparatus. The greatest advantage, however, lies in the fact that it is impossible for an outsider to "overhear" or "tap" a message. The lack of secrecy has always been one of the disadvantages urged against wireless telegraphy as an argument against its commercial utility, but it is possible that this system, or some modification of it, may present advantages in certain cases.

Anders Bull has also suggested methods for rendering messages unintelligible to those unconcerned; one is to make the intervals of time between the impulses in the series so long that the latter become somewhat longer than the intervals between each of the series, which are despatched in continuous succession when the key is pressed for a dash. This is the case with the series S_3 in Fig. 76. When telegraphing, the series will then overlap each other in a way which makes the message unintelligible if recorded in the usual manner. This is plain from tapes IV. and V. (Fig. 78), which were simultaneously unwound from two Morse machines, one being tuned and the other connected to the coherer in the ordinary way. The latter machine, of course, registers each impulse in the order of arrival, and the message appears as on tape V. Tape IV. is the identical message recorded by the tuned receiver, and it should be observed that the series in this case only consisted of three impulses. When a greater number is chosen the messages recorded by an ordinary receiver will be still more confused. The other way of keeping the messages secret is to use short series, as S_1 and S_2 in Fig. 76, and to send out in the spaces between the individual dots and dashes of the message a series of a form not affecting the receiver telegraphed to, but nevertheless resembling the series to which the receiver is tuned; this can be done by a very simple automatic device. In such a case an ordinary wireless telegraph receiver would give an unbroken row of dots, quite impossible to decipher, as the two forms of series could not be separated.

The following is an account of some tests carried out before the United States Navy with the Anders Bull system of selective wireless telegraphy, described in *The Electrician*, vol. xlvi. p. 573; vol. l. p. 418; and vol. li. p. 963. The tests were undertaken between the Government stations at Highlands of Navesink, N.J., and Brooklyn Navy Yard, the distance being about thirty-five kilometres. The field is considered a rather difficult one for experimental work, as the waves have to pass the greater part of Brooklyn; moreover, the

stations are very much troubled by interference from several other wireless installations in the neighbourhood, the interference lasting sometimes without interruption for hours.

The regular service between the said two stations is performed by means of the Slaby-Arco system, which has been provisionally adopted by the United States Navy. It was decided to try the Anders Bull selective instruments in connection with the existing installation. The instruments were employed as already described. The voltage used at Navesink and Brooklyn is 80 and 110 volts respectively; as, however, the transmitter was only constructed for low voltage and small power, it was only possible to use a fraction of the energy generally employed for signalling between the stations. Thus, while the spark is usually about $\frac{3}{4}$ inch long, the tests had to be made with $\frac{5}{32}$ inch spark. In order to get good communication, it was necessary to make the receiving arrangement very sensitive. This, however, made the conditions for the tests rather unfavourable, as sensitive instruments are much more exposed to disturbances of all kinds, and do not work with the same exactness and rapidity as less sensitive ones. Of course, difficulties of this nature can be easily overcome, as the transmitter can be constructed for any energy required; but for the tests in question no other apparatus was at hand.

The transmitter was installed at Navesink, the receiver at Brooklyn Navy Yard. Lack of apparatus prevented them from signalling selectively in both directions. At both places switches were provided, so that either the Slaby instruments or the Anders Bull apparatus could be connected up to the oscillation circuits and aerials.

The experiments were conducted chiefly with a view to demonstrating the *secrecy* of the correspondence. Arrangements were, therefore, made at the receiving station so that the messages could be simultaneously registered by the selective inker M, and another one, M′, which was connected up to a relay in the ordinary way, thus enabling a comparison to be made between the two records. Secrecy was obtained by using a series of three impulses at intervals of 0·063 and 0·295 second, the interval between successive series being 0·2 second.

The official demonstration was conducted before the Wireless Telegraph Board. The sending was carried out by the chief electrician at the Navesink station. During the tests there were slight atmospheric disturbances, which seemed strongly to affect the communication with the Slaby-Arco instruments, while they had only very little effect on the selective signalling. A message which could not be read, in spite of its being repeated some four or five times with the Slaby instruments, was easily deciphered when sent once by the Anders Bull. In order to put the selective inker in action, at least three wave impulses correctly timed are necessary. As long as, therefore, the interference is only moderate it does not affect the selective receiver, although it may be strong enough to make correspondence with ordinary wireless instruments an impossibility. To prevent misunderstanding, it should be observed that the Slaby instruments were using the full energy the whole time. Very long

despatches were after this satisfactorily transmitted with the Anders Bull instruments, the operator at times working the key without interruption for fifteen minutes. Some tests were also performed for the purpose of ascertaining the influence of a difference in the speeds of the transmitting and receiving instruments respectively. The speed of the disperser was kept constant at 57 revolutions per minute, while the collector was made to run with speeds varying between 53·5 and 61 revolutions per minute. During the whole time the V's sent by the Navesink station came out very clearly on the tape of the selective inker. Thus, even deviations from the normal speed as great as 8 per cent. could be allowed. It is advisable, however, in order to get a distinct tuning, that the variations should be the smallest possible.

Comparisons between the tapes unrolled by the selective inker M, and the ordinary one, M′, proved the complete impossibility of outsiders tapping the messages. Any wireless signalling is apt to be interfered with, especially when carried out over long distances. Some dots may fail, new ones may appear (for instance, by atmospheric disturbances), or a dash may be split up into dots; in this way letters may easily be mistaken. As long as ordinary language is used scattered faults of this kind are not of much importance, as they are generally easily detected by the context of the message. When code is used the case is different. The mistake of a few letters may here make the whole message illegible. Besides, the use of code requires skill, and is very time-wasting work, even if the messages come in perfectly clear, and there may be occasions where the minutes are valuable; for instance, during war.

Another system for which an advantage is claimed in connection with syntonic telegraphy is that of Alessandro Artom, who has proposed to employ a circularly or elliptically polarized beam of electric radiation.

This inventor has described in two British patent specifications his appliances, as follows.[51] He erects two aerial wires at right angles both at 45° to the vertical. In these aerials he states that he can generate by the usual method of condenser discharge oscillations which differ in phase by 90°. It is not very clear from the specifications that the methods he proposes would be effective, because the patentee appears to neglect the fact that the radiation sent out from a linear aerial is very highly damped. To procure approximately circular polarization, it is necessary that the original beam of radiation shall have been polarized in one plane and then split into two beams polarized in planes at right angles, and one of these beams he retarded by 90° or a quarter of a period. Optically this is affected by a device called a Fresnel's rhomb. In the electrical case it is necessary to secure that the oscillations in the two aerials at right angles are not only in the right relative phase at the commencement of the oscillations, but remain different in phase by 90° throughout the train of waves, and also that both trains have the same logarithmic decrement. It is also not very clear what advantage is secured by the use of a beam of circularly or elliptically polarized radiation in regard to the

[51] See British Patent Specifications of Alessandro Artom, No. 26,395, of November 29, 1902, and No. 9408, of April 25, 1903.

privacy of communication. The method appears, however, to have been tested in Italy by the officers of the Italian Navy, with the following results, as stated in a letter addressed to the chairman of the Royal Academy of Lincei by the inventor.

It has been said that experiments were conducted in the Gulf of Spezia in February, 1903, to test the feasibility of signalling from the wireless telegraph station of St. Vito to that of St. Bartolomeo (a distance of 4 kilometres), without its being possible for the lateral stations of Varignano and Palmaria, situated a few kilometres outside the junction of the transmitting station of St. Vito with the receiving one of St. Bartolomeo, to receive any signal.

Further experiments were conducted between the radiotelegraphic station of Monte Mario (Rome) and Anzio (a distance of 60 kilometres) in the months of August, October, and November, 1903, with the same object.

The patentee asserts that when the radiator was turned towards Anzio the signals were received perfectly, whilst they ceased when, the energy employed being the same, the radiator was turned towards Sardinia.

Experiments were also tried in the months of March and April, 1904, between the wireless telegraph station of Monte Mario (Rome) and that of Ponza (a distance of 120 kilometres). It is said to have been ascertained that it was possible to send very clear signals to the receiving station of Ponza, and that one could also treble the energy wherewith such electromagnetic signals were produced, without its being possible for the receiving station located in the island of Maddalena, and situated laterally outside the junction of Monte Mario with the island of Ponza, to perceive any signal.

Experiments executed in the months of August, October, November, and December, 1904, between the wireless telegraph station of Monte Mario (Rome) and that of the island of Maddalena (a distance of 260 kilometres). These experiments are asserted to have confirmed the preceding ones.

It will be interesting to know if further researches confirm the advantage said to be obtained by the employment of such circularly polarized electromagnetic radiation.

On the whole, however, it cannot be said that any of the proposed substitutes for true electric resonance, as a means of securing the privacy of wireless telegraphic communication, have been very successful. Either they involve apparatus of considerable complexity, or else they fail to fulfil in practice the hopes of their inventors, by reason of the fact that the said inventors lose sight of the fact that much which is possible with continuous radiation ceases to be possible when we are dealing with intermittent trains of damped waves.

The systems which give greatest promise of privacy for naval use are those which, like that of Anders Bull, depend upon the emission of properly spaced trains of waves, a group of these constituting the elementary signal or *dot* of the Morse code.

For naval and war purposes the speed of transmission of a message is not nearly so important as its absolute privacy, and the impossibility of an enemy mutilating the record, or preventing the reception.

A great deal of information can be compressed into a single word

by the use of a code, but then the absolute accuracy of every signal becomes supremely important.

For this purpose, also, automatic sending by punched tapes has a great advantage. The message can be punched in sections and carefully read before being passed through the transmitter, and can be sent several times over with absolute accuracy as regards spacing and lettering.

It is a well-known fact that the majority of messages (90 per cent.) sent by submarine cable are in code, and often the change of a letter would involve serious or costly mistakes. Hence, although hand sending and ear reception by telephone have great advantages for the ordinary conversational or even press news messages, there can be no doubt but that for the transmission of commercial messages on which financial results depend, accuracy is the more important quality, and no matter what the speed or distance, confidence will not be obtained unless the communicators are assured by experience of the same degree of accuracy with wireless transmission as with submarine cable transmission generally.

When, however, we remember that submarine cable telegraphy has more than fifty years' experience behind it, whilst electric wave radio telegraphy has not yet fourteen, we may well take encouragement from the great progress of the latter to believe that still more important achievements are in store for the method of telegraphy by unguided electromagnetic waves.

23. Legislation on the Subject of Wireless Telegraphy.—The increasing importance of wireless telegraphy in connection with naval operations caused the principal maritime powers in the world to make it a subject of legislation between 1900 and 1904. In addition, the work of the Marconi Wireless Telegraph Company, in organizing a splendid system of inter-communications between ships at sea and the shore, and its increasing importance, naturally drew the attention of other nations to the commercial value of this form of telegraphy.

With the professed object of increasing these public facilities, the German Government called an International Conference on the subject of wireless telegraphy in 1903, which commenced its sittings in the Imperial Post Office at Berlin, in August, 1903. Representatives from the European Powers and the United States were invited to assemble and discuss the subject of International Legislation of Wireless Telegraphy, with the ostensible purpose of eliminating special interests and developing the art for the common benefit of seafaring people.

At this Conference, representatives of Great Britain, the United States, France, Germany, Italy, Austria-Hungary, Russia, and Spain, were in attendance, and the secretary of the German Post Office opened the proceedings.

The German proposals were then laid before the Conference by Herr Sydow, Under-Secretary of the Post Office. The motive which prompted the issuance of an invitation to this Conference on the part of the German Government was undoubtedly the desire to prevent, if possible, a ship to shore telegraphy from falling entirely into the hands of a single corporation or country.

The Marconi Wireless Telegraph Company of England, formed to

conduct and apply commercially Mr. Marconi's inventions, was naturally not administered on purely altruistic principles, but being a commercial organization, and having made a large expenditure of its shareholders' money in bringing these inventions into a condition in which they could become commercially remunerative, looked for an adequate return on the capital so expended. By skilful management and wise prevision, they had entered into contracts with foreign and Colonial Governments, as well as with the Corporation of Lloyds, the result being to build up a splendid organization securing the utmost possible facility and unity for maritime communications by means of electric wave wireless telegraphy.

The German Government were anxious to secure that all wireless telegraph messages to and from ships should be taken and transmitted without distinction of systems, that is to say, that a Marconi coast installation, say in England, or on a ship at sea, should be bound to send messages to, or accept messages from, a ship equipped with German apparatus. Such a free use, however, of the Marconi system and organization by foreign competitors would no doubt have been very advantageous to them, but it does not follow that the public interests would have been better served, whilst a grave injustice would have been done to those who had borne the burden of creating the system and appliances necessary for bringing this invention into practical use.

The result of the Conference was that the majority of the representatives of the European Powers adopted two resolutions, which it was hoped might afford a basis for a further conference. These were as follows:—

1. The coast stations should be obliged to receive and transmit all telegrams from and to ships at sea, without respect to the system, in order to facilitate communication between the ships and stations. As far as possible, all necessary technical information as to their equipment should be published. It should be the duty of these stations to give precedence to telegrams relating to shipwrecks and appeals for help for ships. It is further provided that the States in question should fix a tariff for forwarding communications which should be based on the tariff now in force for ordinary telegrams, plus a special charge for the use of wireless telegraph telegrams, the latter charge fixed at such a figure that the due remuneration is paid for the services of wireless telegraphy. Tariffs shall in all cases be based on the number of words. The rates are to be fixed with the consent of the company on which the land stations are, or the country whose flag is carried by the ships' stations.

2. In other respects it is provided that the wireless telegraph service shall be so regulated that the individual stations disturb one another as little as possible.

A number of technical provisions were also made, intended to secure the best and most profitable working of wireless telegraphy.

A protocol agreeing with the above resolutions was signed by representatives of Germany, Austria-Hungary, Spain, United States, France, and Russia. The United States pointed out, however, that American law would prevent the Government from forbidding the company to erect a signalling station because that company refused

to exchange telegrams with stations in another country equipped with a different system.

Great Britain and Italy took up a different position. The Italian Government having already entered into an agreement with Mr. Marconi to use his system exclusively for fourteen years, and not to exchange telegrams with stations equipped with other systems, the Italian delegates were consequently prevented from agreeing to the above resolution or to that part of it which would be in contravention with this agreement.

The British delegates intimated that they would lay the results of the preliminary Conference before their Government; they took exception particularly to the first article of the protocol.

Although it was intended that this Conference should be the precursor of another, yet it is clear that German diplomacy has not been entirely successful in bringing about the desired result as a consequence of this preliminary Conference.

In the year 1904 the British Government felt the importance of controlling by legislation the use of wireless telegraphy, so that irregular or nefarious operations might be prevented. An Act was accordingly passed through the two Houses of Parliament and received the Royal Assent in August, 1904, entitled "An Act to provide for the Regulation of Wireless Telegraphy" (August 15, 1904).

In this Act (see Appendix I.) it was provided that no person should establish or work a wireless telegraph apparatus in Great Britain or on a British ship except under licence from the Postmaster-General. Licences were to be granted either for commercial purposes or ship to shore communications, or else under regulation for purely experimental purposes. It was furthermore decreed that this Act should continue in force until July, 1906, and no longer, unless Parliament otherwise determines.

In February, 1906, an Amendments Act was passed, extending the operation of the Act of 1904 for a further six years.

In 1906 the German Government again issued an invitation to all the Powers to meet a second time in conference at Berlin and discuss an International Convention on wireless telegraphy. This Conference commenced its sittings in October, 1906, and was attended by representatives of the following Governments: Argentina, Austria-Hungary, Belgium, Brazil, Bulgaria, Chili, Denmark, Egypt, France, Germany, Greece, Great Britain, Italy, Japan, Mexico, Monaco, Montenegro, Netherlands, Norway, Persia, Portugal, Roumania, Russia, Siam, Spain, Sweden, the United States, and Uruguay.

The Conference had before it for consideration the text of a convention providing regulations for the international control of radiotelegraphy, which was discussed article by article. The chief discussion turned round Article 3, which provided that coast stations and ship stations are to be bound to exchange radiotelegrams regardless of the system used in them. Other articles dealt with the definition of wave lengths to be employed for particular services and regulations of working, and also with the creation of an International Bureau for collecting and diffusing information. The Convention having been provisionally agreed to by the representatives of the several Powers with certain modifications, it was referred to

the respective Governments for ratification. Objections were raised in Parliament to ratification by the British Government, and the House of Commons thereupon appointed a Select Committee to report to it on the recommendations of the International Berlin Conference of 1906. This Committee commenced its sittings in April, 1907, under the Chairmanship of Sir John Dickson-Poynder. Evidence was offered for and against ratification by Government officials, representatives of the Marconi Company, and others concerned. This Committee drew up a report, which was issued in November, 1907, as a Parliamentary Blue-book.

By a majority of one in a Committee of eleven members they recommended ratification on behalf of the British Government. This ratification took effect on and from July 1, 1908.

The text of the agreed International Service regulations is given in Appendix II.

In September, 1909, an agreement was made between Marconi's Wireless Telegraph Company and the Marconi International Marine Communication Company and the Postmaster-General, whereby in consideration of the sum of £15,000 the Companies transferred to the Post Office certain Coast Stations which from January 1, 1910, were taken over and worked by the British Post Office (see *The Electrician*, vol. 64, p. 639, January 28, 1910).

WIRELESS TELEGRAPHIC COMMUNICATION

Guglielmo Marconi

GUGLIELMO MARCONI

Wireless telegraphic communication

Nobel Lecture, December 11, 1909

The discoveries connected with the propagation of electric waves over long distances and the practical applications of telegraphy through space, which have gained for me the high honour of sharing the Nobel Prize for Physics, have been to a great extent the results of one another.

The application of electric waves to the purposes of wireless telegraphic communication between distant parts of the earth, and the experiments which I have been fortunate enough to be able to carry out on a larger scale than is attainable in ordinary laboratories, have made it possible to investigate phenomena and note results often novel and unexpected.

In my opinion many facts connected with the transmission of electric waves over great distances still await a satisfactory explanation, and I hope to be able in this lecture to refer to some observations, which appear to require the attention of physicists.

In sketching the history of my association with radiotelegraphy, I might mention that I never studied physics or electrotechnics in the regular manner, although as a boy I was deeply interested in those subjects.

I did, however, attend one course of lectures on physics under the late Professor Rosa at Livorno, and I was, I think I might say, fairly well acquainted with the publications of that time dealing with scientific subjects including the works of Hertz, Branly, and Righi.

At my home near Bologna, in Italy, I commenced early in 1895 to carry out tests and experiments with the object of determining whether it would be possible by means of Hertzian waves to transmit to a distance telegraphic signs and symbols without the aid of connecting wires.

After a few preliminary experiments with Hertzian waves I became very soon convinced, that if these waves or similar waves could be reliably transmitted and received over considerable distances a new system of communication would become available possessing enormous advantages over flashlights and optical methods, which are so much dependent for their success on the clearness of the atmosphere.

My first tests were carried out with an ordinary Hertz oscillator and a

Branly coherer as detector, but I soon found out that the Branly coherer was far too erratic and unreliable for practical work.

After some experiments I found that a coherer constructed as shown in Fig. 1, and consisting of nickel and silver filings placed in a small gap between two silver plugs in a tube, was remarkably sensitive and reliable. This improvement together with the inclusion of the coherer in a circuit tuned to the wavelength of the transmitted radiation, allowed me to gradually extend up to about a mile the distance at which I could affect the receiver.

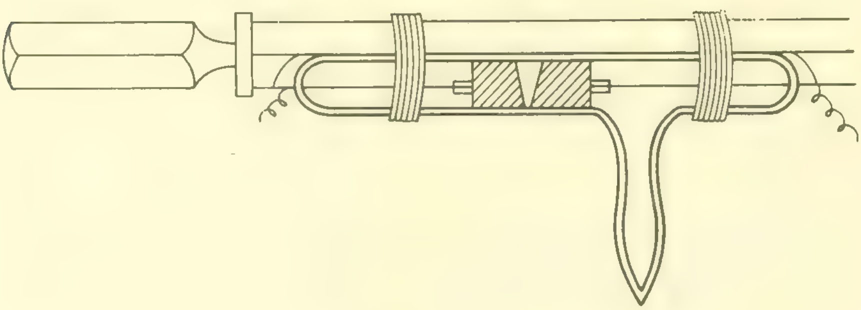


Fig. 1.

Another, now well-known, arrangement which I adopted was to place the coherer in a circuit containing a voltaic cell and a sensitive telegraph relay actuating another circuit, which worked a tapper or trembler and a recording instrument. By means of a Morse telegraphic key placed in one of the circuits of the oscillator or transmitter it was possible to emit long or short successions of electric waves, which would affect the receiver at a distance and accurately reproduce the telegraphic signs transmitted through space by the oscillator.

With such apparatus I was able to telegraph up to a distance of about half a mile.

Some further improvements were obtained by using reflectors with both the transmitters and receivers, the transmitter being in this case a Righi oscillator.

This arrangement made it possible to send signals in one definite direction, but was inoperative if hills or any large obstacle happened to intervene between the transmitter and receiver.

In August 1895 I discovered a new arrangement which not only greatly increased the distance over which I could communicate, but also seemed to make the transmission independent from the effects of intervening obstacles.

This arrangement (Figs. 2 and 3) consisted in connecting one terminal of the Hertzian oscillator, or spark producer, to earth and the other terminal to a wire or capacity area placed at a height above the ground, and in also connecting at the receiving end one terminal of the coherer to earth and the other to an elevated conductor.

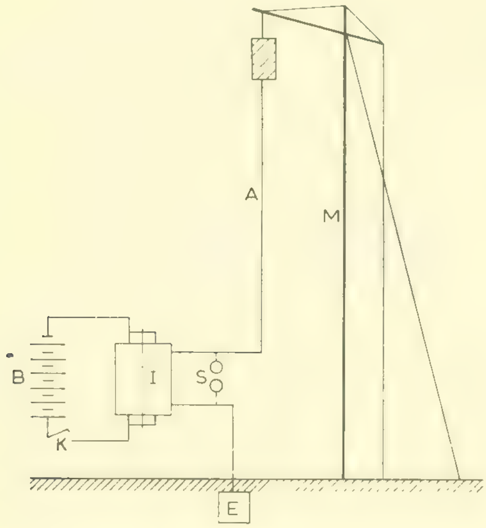


Fig. 2.

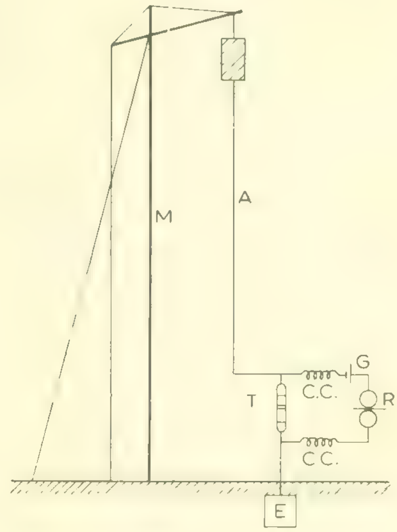


Fig. 3.

I then began to examine the relation between the distance at which the transmitter could affect the receiver and the elevation of the capacity areas above the earth, and I very soon definitely ascertained that the higher the wires or capacity areas, the greater the distance over which it was possible to telegraph.

Thus I found that when using cubes of tin of about 30 cm side as elevated conductors or capacities, placed at the top of poles 2 meters high, I could receive signals at 30 meters distance, and when placed on poles 4 meters high, at 100 meters, and at 8 meters high at 400 meters. With larger cubes 100 cm side, fixed at a height of 8 meters, signals could be transmitted 2,400 meters all round.[1]

These experiments were continued in England, where in September 1896 a distance of $1\frac{3}{4}$ miles was obtained in tests carried out for the British Government at Salisbury. The distance of communication was extended to 4 miles in March 1897, and in May of the same year to 9 miles. Tape messages obtained during these tests, signed by the British Government Officers who were present, are exhibited.[2]

In all these experiments a very small amount of electrical power was used,

the high tension current being produced by an ordinary Rhumkorff coil.

The results obtained attracted a good deal of public attention at the time, such distances of communication being considered remarkable.

As I have explained, the main feature in my system consisted in the use of elevated capacity areas or antennae attached to one pole of the high frequency oscillators and receivers, the other pole of which was earthed.

The practical value of this innovation was not understood by many physicists[3] for quite a considerable period, and the results which I obtained were by many erroneously considered simply due to efficiency in details of construction of the receiver, and to the employment of a large amount of energy.

Others did not overlook the fact that a radical change had been introduced by making these elevated capacities and the earth form part of the high frequency oscillators and receivers.

Prof. Ascoli of Rome gave a very interesting theory of the mode of operation of my transmitters and receivers in the *Elettricista (Rome)* issue of August 1897, in which he correctly attributed the results obtained to the use of elevated wires or antennae.

Prof. A. Slaby of Charlottenburg, after witnessing my tests in England in 1897, came to somewhat similar conclusions.[4]

Many technical writers have stated that an elevated capacity at the top of the vertical wire is unnecessary.

This is true if the length or height of the wire is made sufficiently great, but as this height may be much smaller for a given distance if a capacity area is used, it is more economical to use such capacities, which now usually consist of a number of wires spreading out from the top of the vertical conductor.

The necessity or utility of the earth connection has been sometimes questioned, but in my opinion no practical system of wireless telegraphy exists where the instruments are not connected to earth.

By «connected to earth» I do not necessarily mean an ordinary metallic connection as used for ordinary wire telegraphs.

The earth wire may have a condenser in series with it, or it may be connected to what is really equivalent, a capacity area placed close to the surface of the ground (Fig. 4).

It is now perfectly well known that a condenser, if large enough, does not prevent the passage of high frequency oscillations, and therefore in these cases the earth is for all practical purposes connected to the antennae.

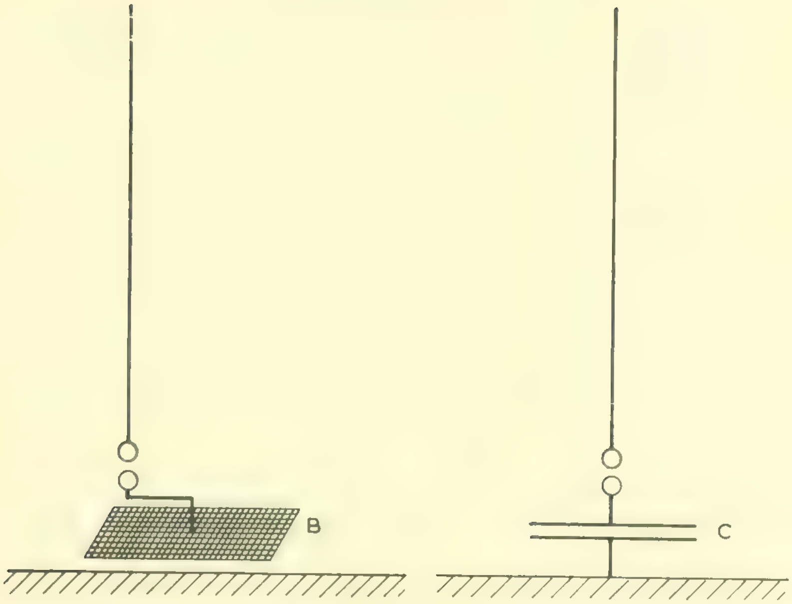


Fig. 4.

After numerous tests and demonstrations in Italy and England over distances varying up to 40 miles, communication was established for the first time across the English Channel between England and France[5] in March 1899 (Fig. 5).

Fig. 5.

From the beginning of 1898 I had practically abandoned the system of connection shown in Fig. 2, and instead of joining the coherer or detector directly to the aerial and earth, I connected it between the ends of the secondary of a suitable oscillation transformer containing a condenser and tuned to the period of the electrical waves received. The primary of this oscillation transformer was connected to the elevated wire and to earth (See Fig. 6.)

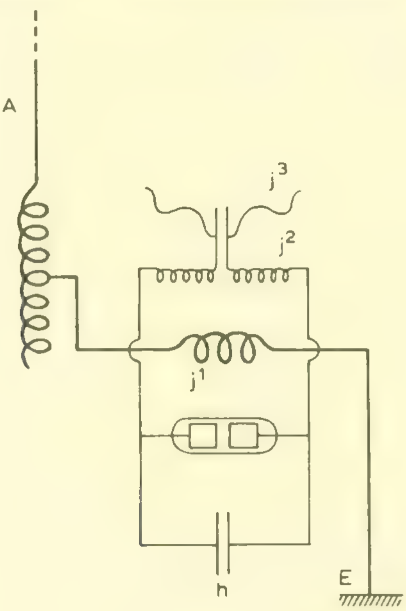


Fig. 6.

This arrangement allowed of a certain degree of syntony, as by varying the period of oscillation of the transmitting antennae, it was possible to send messages to a tuned receiver without interfering with others differently syntonized.[6]

As is now well known, a transmitter consisting of a vertical wire discharging through a spark gap is not a very persistent oscillator, the radiation it produces being considerably damped. Its electrical capacity is comparatively so small and its capability of radiating energy so large, that the oscillations decrease or die off with rapidity. In this case receivers or resonators of a considerably different period or pitch are likely to be affected by it.

Early in 1899 I was able to improve the resonance effects obtainable by increasing the capacity of the elevated wires by placing adjacently to them earthed conductors, and inserting in series with the aerials suitable inductance coils.[7]

By these means the energy-storing capacity of the aerial was increased,

whilst its capability to radiate was decreased, with the result that the energy set in motion by the discharge formed a train or succession of feebly damped oscillations.

A modification of this arrangement, by which excellent results were obtained, is shown in Fig. 7.

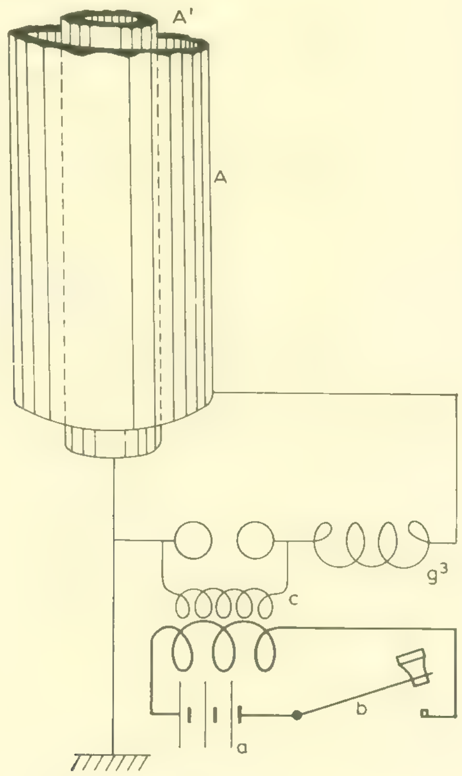


Fig. 7.

In 1900 I constructed and patented a complete system of transmitters and receivers[8] which consisted of the usual kind of elevated capacity area and earth connection, but these were inductively coupled to an oscillation circuit containing a condenser, an inductance, and a spark gap or detector, the conditions which I found essential for efficiency being that the periods of electrical oscillation of the elevated wire or conductor should be in tune or resonance with that of the condenser circuit, and that the two circuits of the receiver should be in electrical resonance with those of the transmitter (Fig. 8).

The circuits consisting of the oscillating circuit and the radiating circuit were more or less closely «coupled» by varying the distance between them.

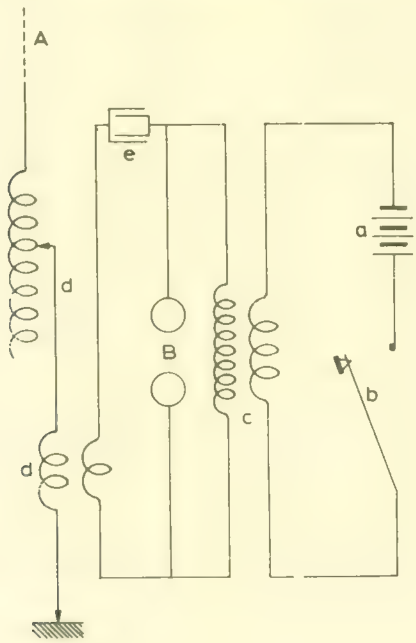


Fig. 8.

By the adjustment of the inductance inserted in the elevated conductor and by the variation of capacity of the condenser circuit, the two circuits were brought into resonance, a condition which, as I have said, I found essential in order to obtain efficient radiation.

Part of my work regarding the utilization of condenser circuits in association with the radiating antennae was carried out simultaneously to that of Prof. Braun, without, however, either of us knowing at the time anything of the contemporary work of the other.

A syntonic receiver has already been shown in Fig. 6, and consists of a vertical conductor or aerial connected to earth through the primary of an oscillation transformer, the secondary circuit of which included a condenser and a detector, it being necessary that the circuit containing the aerial and the circuit containing the detector should be in electrical resonance with each other, and also in tune with the periodicity of the electric waves transmitted from the sending station.

In this manner it was possible to utilize electric waves of low decrement and cause the receiver to integrate the effect of comparatively feeble but properly timed electrical oscillations in the same way as in acoustics two tuning forks can be made to affect each other at short distances if tuned to the same period of vibration.

It is also possible to couple to one sending conductor several differently tuned transmitters and to a receiving wire a number of corresponding receivers, as is shown in Figs. 9 and 10, each individual receiver responding

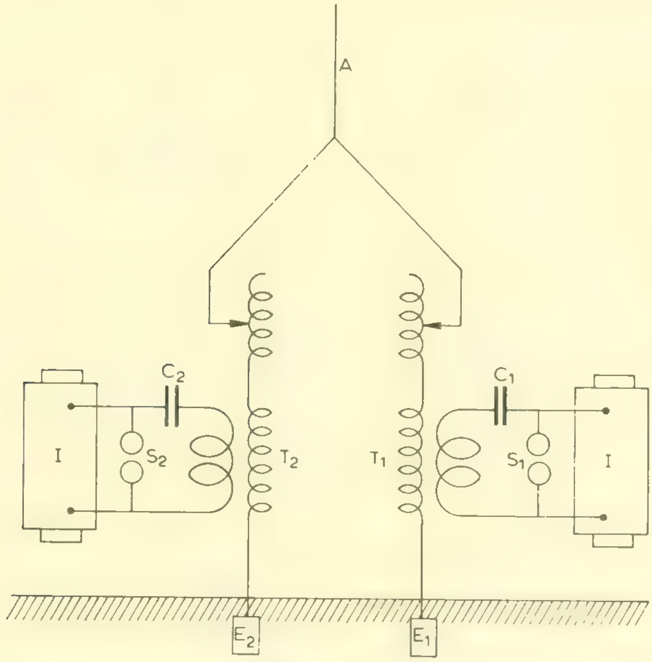


Fig. 9.

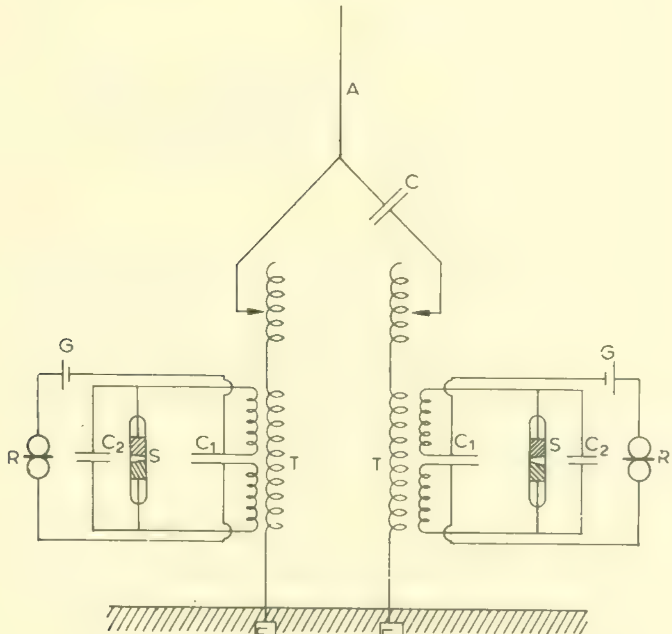


Fig. 10.

only to the radiations of the transmitter with which it is in resonance.[9]

At the time (twelve years ago) when communication was first established by means of radiotelegraphy between England and France, much discussion and speculation took place as to whether or not wireless telegraphy would be practicable for much longer distances than those then covered, and a somewhat general opinion prevailed that the curvature of the Earth would be an insurmountable obstacle to long distance transmission, in the same way as it was, and is, an obstacle to signalling over considerable distances by means of light flashes.

Difficulties were also anticipated as to the possibility of being able to control the large amount of energy which it appeared would be necessary to cover long distances.

What often happens in pioneer work repeated itself in the case of radiotelegraphy, the anticipated obstacles or difficulties were either purely imaginary or else easily surmountable, but in their place unexpected barriers manifested themselves, and recent work has been mainly directed to the solution of problems presented by difficulties which were certainly neither expected nor anticipated when long distances were first attempted.

With regard to the presumed obstacle of the curvature of the Earth, I am of opinion that those who anticipated difficulties in consequence of the shape of our planet had not taken sufficient account of the particular effect of the earth connection to both transmitter and receiver, which earth connection introduced effects of conduction which were generally at that time overlooked.

Physicists seemed to consider for a long time that wireless telegraphy was solely dependent on the effects of free Hertzian radiation through space, and it was years before the probable effect of the conductivity of the Earth between the stations was satisfactorily considered or discussed.

Lord Rayleigh, in referring to transatlantic telegraphy, stated in May 1903: « The remarkable success of Marconi in signalling across the Atlantic

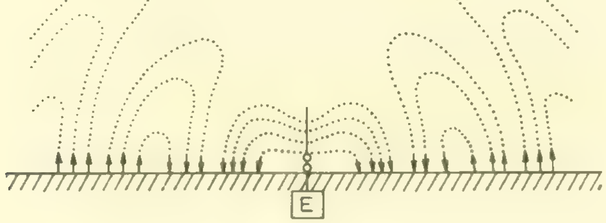


Fig. 11.

suggests a more decided bending or diffraction of the waves round the perturberant Earth than had been expected, and it imparts a great interest to the theoretical problem[10].

Prof. J. A. Fleming, in his book on *The Principles of Electric Wave Telegraphy*[11], gives diagrams showing what is now believed to be the diagrammatic representation of the detachment of semi-loops of electric strain from a simple vertical wire (Fig. 11). As will be seen, these waves do not propagate in the same manner as free radiation from a classical Hertzian oscillator, but glide along the surface of the Earth.

Prof. Fleming further states in the above quoted work:

« The view we here take is that the ends of the semi-loops of electric force, which terminate perpendicularly on the Earth, cannot move along unless there are movements of electrons in the Earth corresponding to the wave-motions above it. From the point of view of the electronic theory of electricity, every line of electric force in the ether must be either a closed line or its ends must terminate on electrons of opposite sign. If the end of a line of strain abuts on the Earth and moves, there must be atom-to-atom exchange of electrons, or movements of electrons in it. We have many reasons for concluding that the substances we call conductors are those in which free movements of electrons can take place. Hence the movements of the semi-loops of electric force outwards from an earthed oscillator or Marconi aerial is hindered by bad conductivity on the surface of the Earth and facilitated over the surface of a fairly good electrolyte, such as sea-water. »

Prof. Zenneck[12] has carefully examined the effect of earthed transmitting and receiving aerials, and has endeavoured to show mathematically that when the lines of electrical force, constituting a wave front, pass along a surface of low specific inductive capacity, such as the Earth, they become inclined forward, their lower ends being retarded by the resistance of the conductor to which they are attached.

It therefore seems well established that wireless telegraphy, as practised at the present day, is dependent for its operation over long distances on the conductivity of the Earth, and that the difference in conductivity between the surface of the sea and land is sufficient to explain the increased distance obtainable with the same amount of energy in communicating over sea as compared to over land.

I carried out some tests between a shore station and a ship at Poole, in England, in 1902, for the purpose of obtaining some data on this point, and I noticed that at equal distances a perceptible diminution in the energy of the

received waves always occurred when the ship was in such a position as to allow a low spit of sand about 1 kilometer broad to intervene between it and the land station.

I therefore believe that there was some foundation for the statement so often criticized which I made in my first English Patent of June 2, 1896 to the effect that when transmitting through the earth or water I connected one end of the transmitter and one end of the receiver to earth.

In January 1901 some successful experiments[13] were carried out between two points on the South Coast of England 186 miles apart, i.e. St. Catherines' Point (Isle of Wight) and The Lizard in Cornwall (Fig. 12).

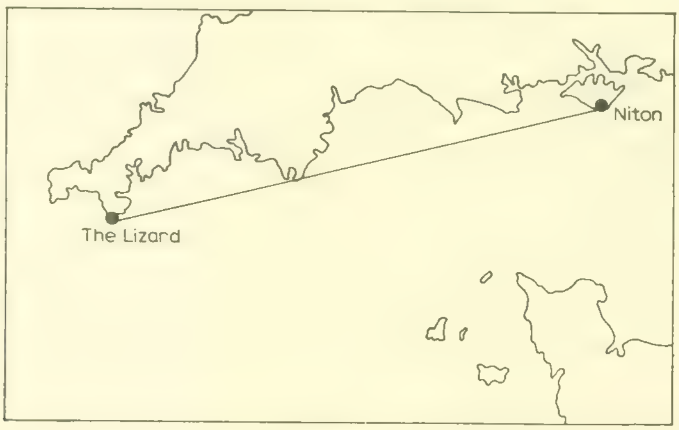


Fig. 12.

The total height of these stations above sea level did not exceed 100 meters, whereas to clear the curvature of the Earth a height of more than 1,600 meters at each end would have been necessary.

The results obtained from these tests, which at the time constituted a record distance, seemed to indicate that electric waves produced in the manner I had adopted would most probably be able to make their way round the curvature of the Earth, and that therefore even at great distances, such as those dividing America from Europe, the factor of the Earth's curvature would not constitute an insurmountable barrier to the extension of telegraphy through space.

The belief that the curvature of the Earth would not stop the propagation of the waves, and the success obtained by syntonic methods in preventing mutual interference, led me in 1900 to decide to attempt the experiment of testing whether or not it would be possible to detect electric waves over a

distance of 4,000 kilometers, which, if successful, would immediately prove the possibility of telegraphing without wires between Europe and America.

The experiment was in my opinion of great importance from a scientific point of view, and I was convinced that the discovery of the possibility to transmit electric waves across the Atlantic Ocean, and the exact knowledge of the real conditions under which telegraphy over such distances could be carried out, would do much to improve our understanding of the phenomena connected with wireless transmission.

The transmitter erected at Poldhu, on the coast of Cornwall, was similar in principle to the one I have already referred to, but on a very much larger scale than anything previously attempted.[14]

The power of the generating plant was about 25 kilowatts.

Numerous difficulties were encountered in producing and controlling for the first time electrical oscillations of such power. In much of the work I obtained valuable assistance from Prof. J. A. Fleming, Mr. R. N. Vyvyan, and Mr. W. S. Entwistle.

My previous tests had convinced me that when endeavouring to extend the distance of communication, it was not merely sufficient to augment the power of the electrical energy of the sender, but that it was also necessary to increase the area or height of the transmitting and receiving elevated conductors.

As it would have been too expensive to employ vertical wires of great height, I decided to increase their number and capacity, which seemed likely to make possible the efficient utilization of large amounts of energy.

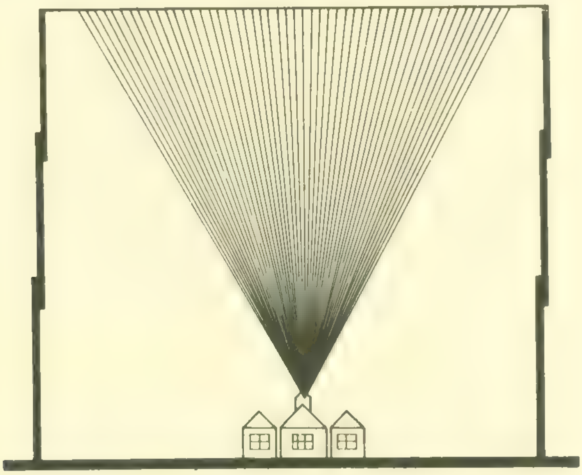


Fig. 13.

The arrangement of transmitting antennae which was used at Poldhu is shown in Fig. 13, and consisted of a fan-like arrangement of wires supported by an insulated stay between masts only 48 meters high and 60 meters apart. These wires converged together at the lower end and were connected to the transmitting apparatus contained in a building.

For the purpose of the test a powerful station had been erected at Cape Cod, near New York, but the completion of the arrangements at that station were delayed in consequence of a storm which destroyed the masts and antennae.

I therefore decided to try the experiments by means of a temporary receiving station erected in Newfoundland, to which country I proceeded with two assistants about the end of November 1901.

The tests were commenced early in December 1901 and on the 12th of that month the signals transmitted from England were clearly and distinctly received at the temporary station at St. John's in Newfoundland.

Confirmatory tests were carried out in February 1902 between Poldhu and a receiving station on the S.S. « Philadelphia » of the American Line. On board this ship readable messages were received by means of a recording instrument up to a distance of 1,551 miles and test letters as far as 2,099 miles from Poldhu (Fig. 14).

The tape records obtained on the « Philadelphia » at the various distances were exceedingly clear and distinct, as can be seen by the specimens exhibited.

These results, although achieved with imperfect apparatus, were sufficient to convince me and my co-workers that by means of permanent stations and the employment of sufficient power it would be possible to transmit messages across the Atlantic Ocean in the same way as they were sent over much shorter distances.

The tests could not be continued in Newfoundland owing to the hostility of a cable company, which claimed all rights for telegraphy, whether wireless or otherwise, in that colony.

A result of scientific interest which I first noticed during the tests on S.S. « Philadelphia » and which is a most important factor in long distance radiotelegraphy, was the very marked and detrimental effect of daylight on the propagation of electric waves at great distances, the range by night being usually more than double that attainable during daytime.[15]

I do not think that this effect has yet been satisfactorily investigated or explained. At the time I carried out the tests I was of opinion that it might be

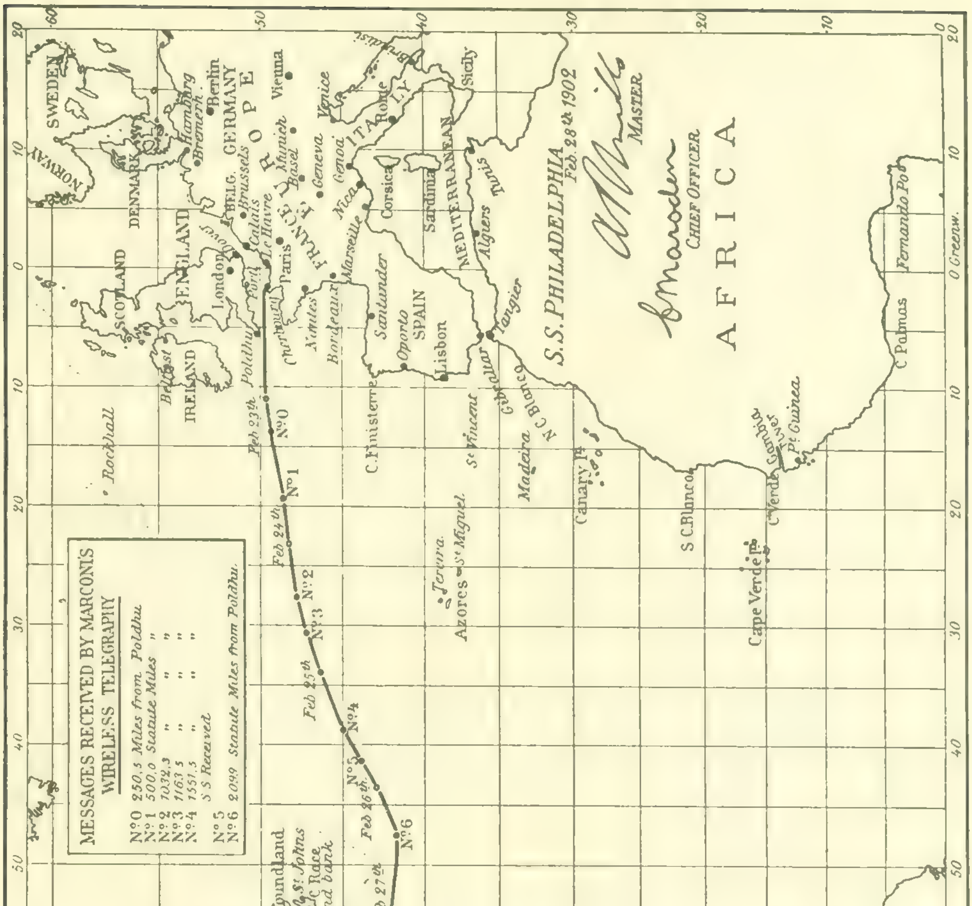


Fig. 14.

due to the loss of energy at the transmitter, caused by the dis-electrification of the highly charged transmitting elevated conductor under the influence of sunlight.

I am now inclined to believe that the absorption of electric waves during the daytime is due to the electrons propagated into space by the sun, and that if these are continually falling like a shower upon the earth, in accordance with the hypothesis of Prof. Arrhenius, then that portion of the Earth's atmosphere which is facing the sun will have in it more electrons than the part which is not facing the sun, and therefore it may be less transparent to electric waves.

Sir J. J. Thomson has shown in an interesting paper in the *Philosophical Magazine* that if electrons are distributed in a space traversed by electric waves, these will tend to move the electrons in the direction of the wave, and will therefore absorb some of the energy of the wave. Hence, as Prof. Fleming has pointed out in his Cantor Lectures delivered at the Society of Arts, a medium through which electrons or ions are distributed acts as a slightly turbid medium to long electric waves.[16]

Apparently the length of wave and amplitude of the electrical oscillations have much to do with this interesting phenomenon, long waves and small amplitudes being subject to the effect of daylight to a much lesser degree than short waves and large amplitudes.

According to Prof. Fleming[17] the daylight effect should be more marked on long waves, but this has not been my experience. Indeed, in some very recent experiments in which waves of about 8,000 meters long were used, the energy received by day was usually greater than at night.

The fact remains, however, that for comparatively short waves, such as are used for ship communication, clear sunlight and blue skies, though transparent to light, act as a kind of fog to these waves. Hence the weather conditions prevailing in England, and perhaps in this country, are usually suitable for wireless telegraphy.

During the year 1902 I carried out some further tests between the station at Poldhu and a receiving installation erected on the Italian Cruiser « Carlo Alberto », kindly placed at my disposal by H.M. The King of Italy. (See Fig. 15.[18])

During these experiments the interesting fact was observed that, even when using waves as short as 1,000 feet, intervening ranges of mountains, such as the Alps or Pyrenees, did not, during the night time, bring about any considerable reduction in the distance over which it was possible to communicate. During daytime, unless much longer waves and more power were used, intervening mountains greatly reduced the apparent range of the transmitter.

Messages and press despatches of considerable length were received from

Fig. 15.

Poldhu at the positions marked on the map, which map is a copy, on a reduced scale, of the one accompanying the official report of the experiments (Fig. 16).

With the active encouragement and financial assistance of the Canadian Government, a high power station was constructed at Glace Bay, Nova Scotia, in order that I should be able to continue my long-distance tests with a view to establishing radiotelegraphic communication on a commercial basis between England and America.[19]

On December 16, 1902 the first official messages were exchanged at night across the Atlantic, between the stations at Poldhu and Glace Bay (Figs. 17 and 18).

Further tests were shortly afterwards carried out with another long-distance station at Cape Cod in the United States of America, and under favourable circumstances it was found possible to transmit messages to Poldhu 3,000 miles away with an expenditure of electrical energy of only about 10 kilowatts.

In the spring of 1903 the transmission of press messages by radiotelegraphy from America to Europe was attempted, and for a time the London *Times* published, during the latter part of March and the early part of April of that year, news messages from its New York correspondent sent across the Atlantic without the aid of cables.

A breakdown in the insulation of the apparatus at Glace Bay made it necessary, however, to suspend the service and unfortunately further accidents made the transmission of messages uncertain and unreliable.

As a result of the data and experience gained by these and other tests which I carried out for the British Government, between England and Gibraltar, I was able to erect a new station at Clifden in Ireland, and enlarge the one at Glace Bay in Canada, so as to enable me to initiate, in October 1907, communication for commercial purposes across the Atlantic between England and Canada.

Although the stations at Clifden and Glace Bay had to be put into operation before they were altogether complete, nevertheless communication across the Atlantic by radiotelegraphy never suffered any serious interruption during nearly two years, until, in consequence of a fire at Glace Bay this autumn, it has had to be suspended for three or four months.

This suspension has not, however, been altogether an unmitigated evil, as

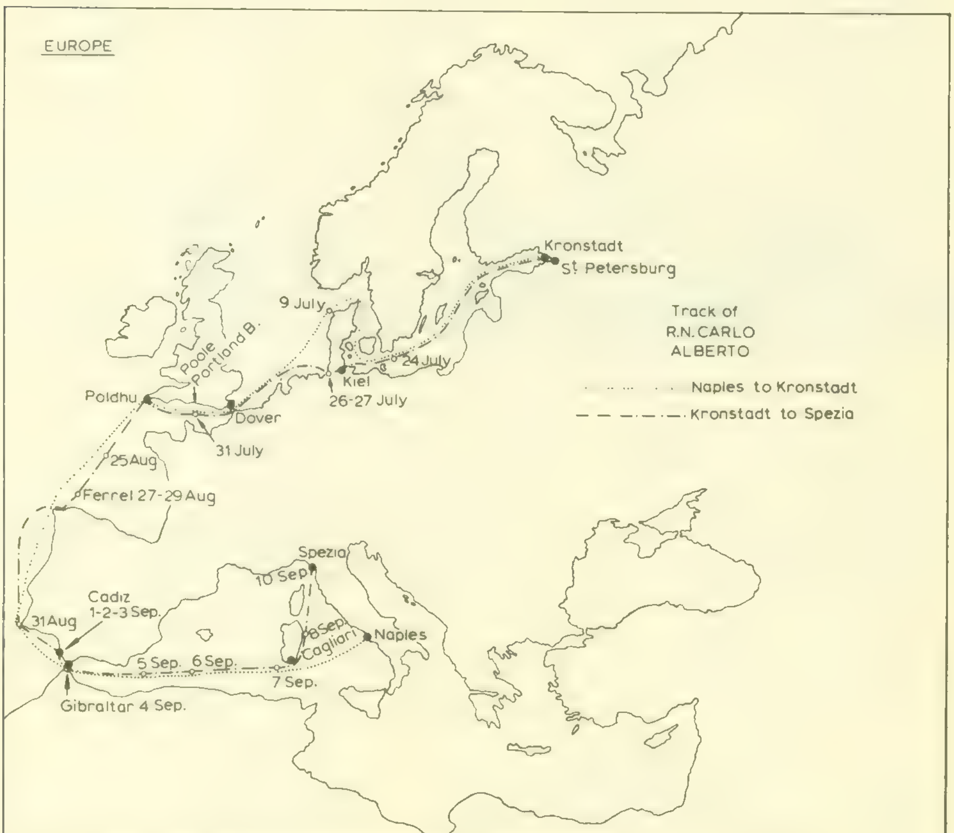


Fig. 16.

Fig. 17.

it has given me the opportunity of installing more efficient and up-to-date machinery.

The arrangements of elevated conductors or aerials which I have tried[20] during my long-distance tests, are shown in Figs. 19, 20 and 21.

The aerial shown in Fig. 21 consisted of a nearly vertical portion in the middle, 220 feet high, supported by four towers, and attached at the top to nearly horizontal wires, 200 in number and each 1,000 feet long, extending radially all round and supported at a height of 180 feet from the ground by an inner circle of 8, and an outer circle of 16 masts.

The natural period of oscillation of this aerial system gave a wavelength of 12,000 feet. Experiments were made with this arrangement in 1905 and with

a wavelength of 12,000 feet, signals, although very weak, could be received across the Atlantic by day as well as by night.

The system of aerial I finally adopted for the long-distance stations in England and Canada is shown in Fig. 22. This arrangement not only makes it possible to efficiently radiate and receive waves of any desired length, but it also tends to confine the main portion of the radiation to a given direction. The limitation of transmission to one direction is not very sharply defined, but the results obtained with this type of aerial are nevertheless exceedingly useful.

Many suggestions respecting methods for limiting the direction of radiating have been made by various workers, notable by Prof. F. Braun, Prof. Artom, and Messrs. Bellini and Tosi.

In a paper read before the Royal Society of London[21] in March 1906 I showed how it was possible by means of horizontal aerials to confine the emitted radiations mainly to the direction of their vertical plane, pointing away from their earthed end.

In a similar manner it is possible to locate the bearing or direction of a sending station.

The transmitting circuits at the long-distance stations are arranged in ac-

Fig. 18.

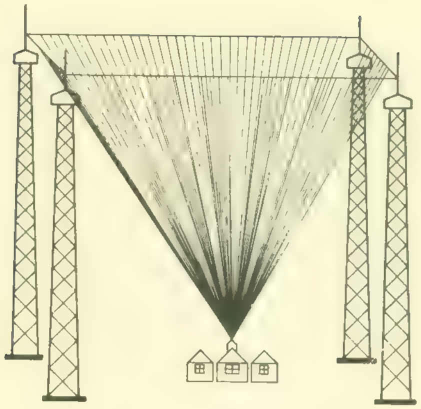


Fig. 19.

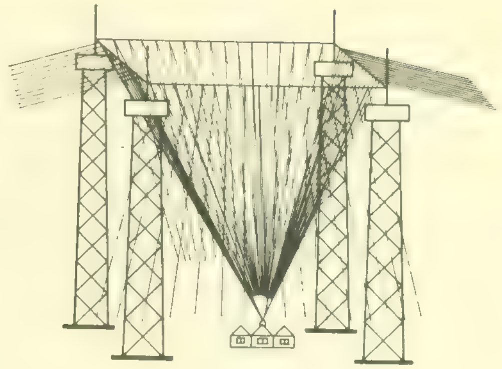


Fig. 20.

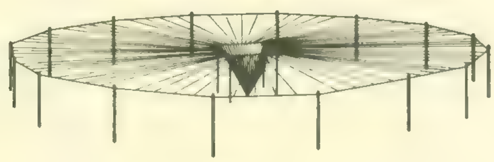


Fig. 21.

Fig. 22.

cordance with a comparatively recent system for producing continuous or slightly damped oscillations, which I referred to in a lecture before the Royal Institution of Great Britain on March 13, 1908.

An insulated metal disc A (see Fig. 23) is caused to rotate at a high rate of speed by means of an electric motor or steam turbine. Adjacent to this disc, which I will call the middle disc, are placed two other discs C′ and C″ which may be called polar discs, and which are also revolved. These polar discs have their peripheries very close to the surface or edges of the middle disc. The two polar discs are connected by rubbing contacts to the outer ends of two condensers K, joined in series, and these condensers are also connected through suitable brushes to the terminals of a generator which should be a high-tension continuous-current generator.

On the middle disc a suitable brush or rubbing contact is provided and between this contact and the middle point of the two condensers an oscillating circuit is inserted, consisting of a condenser E in series with an in-

ductance, which last is inductively connected with the radiating antennae.

The apparatus works probably in the following manner:

The generator charges the double condenser, making the potential of the discs, say C′ positive and C″ negative. The potential, if high enough will cause a discharge to pass across one of the gaps, say between C′ and A. This charges the condenser E through the inductance F, and starts oscillations in the circuit. The charge of F in swinging back will jump from A to C″, the potential of which is of opposite sign to A, the dielectric strength between C′ and A having meanwhile been restored by the rapid motion of the disc, driving away the ionized air.

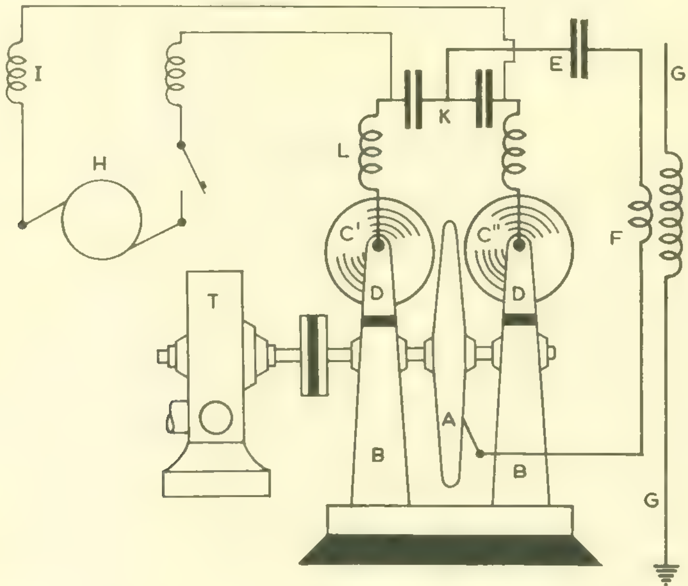


Fig. 23.

The condenser E therefore discharges and recharges alternatively in reverse directions, the same process going on so long as energy is supplied to the condensers K by the generator H.

It is clear that the discharges between C′ and C″ and A are never simultaneous as otherwise the centre electrode would not be alternatively positive and negative.

The best results have, however, been obtained by an arrangement as shown in Fig. 24, in which the active surface of the middle disc is not smooth, but consists of a number of regularly spaced copper knobs or pegs, at the ends of which the discharges take place at regular intervals. I have found that with this arrangement each train of oscillations may have a decrement as low as 0.02.

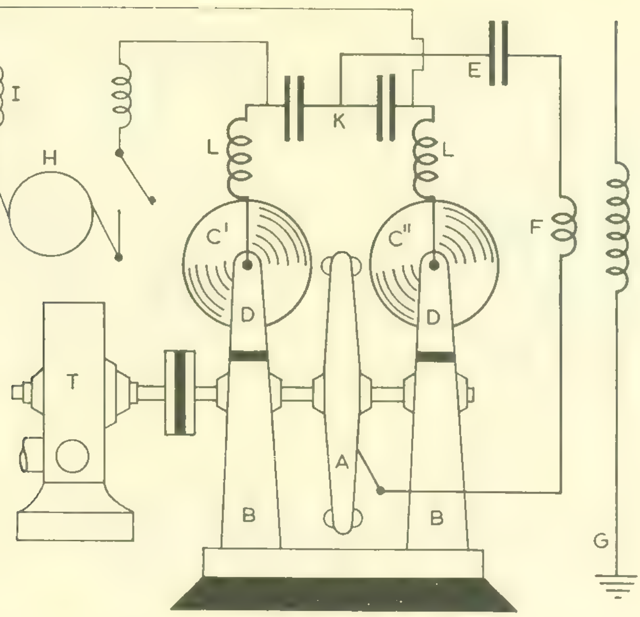


Fig. 24.

In this way it is also possible to cause the groups of oscillations radiated to reproduce a high and clear musical note in a receiver, thereby making it easy to differentiate between the signals emanating from the sending station and noises caused by atmospheric electrical discharges. By this method very efficient resonance can be also obtained in appropriately designed receivers.

With regard to the receivers employed, important changes have taken place. By far the larger portion of electric wave telegraphy was, until a few years ago, conducted by means of some form or other of coherer, or variable contact either requiring tapping or else self-restoring.

At the present day, however, I may say that at all the stations controlled by my Company my *magnetic receiver* (Fig. 25) is almost exclusively employed.[22]

This receiver is based on the decrease of magnetic hysteresis which occurs

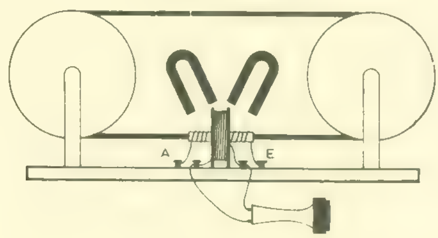


Fig. 25.

in iron when under certain conditions this metal is subjected to the effects of electrical waves of high frequency.

It has recently been found possible to increase the sensitiveness of these receivers, and to employ them in connection with a high-speed relay, so as to record messages at great speed.

A remarkable fact, not generally known, in regard to transmitters is, that none of the arrangements employing condensers exceed in efficiency the plain elevated aerial or vertical wire discharging to Earth through a spark gap, as used in my first experiments (see Figs. 2 and 3).

I have also recently been able to confirm the statement made by Prof. Fleming in his book *The Principles of Electric Wave Telegraphy*, 1906, page 555, that with a power of 8 watts in the aerial it is possible to communicate to distances of over 100 miles.

I have also found that by this method, when using large aerials, it is possible to send signals 2,000 miles across the Atlantic, with a smaller expenditure of energy than by any other method known to myself.

The only drawback to this arrangement is, that unless very large aerials are used, the amount of energy which can be efficiently employed is limited by the potential beyond which brush discharges and the resistance of the spark gap begin to dissipate a large proportion of the energy.

By means of spark gaps in compressed air and the addition of inductance coils placed between the aerial and earth, the system can be made to radiate very pure and slightly damped waves, eminently suitable for sharp tuning.

In regard to the general working of wireless telegraphy, the widespread application of the system and the multiplicity of the stations have greatly facilitated the observation of facts not easily explainable.

Thus it has been observed that an ordinary ship station, utilizing about $\frac{1}{2}$ kilowatt of electrical energy, the normal range of which is not greater than 200 miles, will occasionally transmit messages across a distance of over 1,200 miles. It often occurs that a ship fails to communicate with a nearby station, but can correspond with perfect ease with a distant one.

On many occasions last winter, the S.S. «Caronia» of the Cunard Line, carrying a station utilizing about $\frac{1}{2}$ kilowatt, when in the Mediterranean, off the coast of Sicily, failed to obtain communication with the Italian stations, but had no difficulty whatsoever in transmitting and receiving messages to and from the coasts of England and Holland, although these latter stations were considerably more than 1,000 miles away, and a large part of the continent of Europe and the Alps lay between them and the ship.

Although high power stations are now used for communicating across the Atlantic, and messages can be sent by day as well as by night, there still exist short periods of daily occurrence, during which transmission from England to America, or vice versa, is difficult. Thus in the morning and evening, when in consequence of the difference in longitude, daylight or darkness extends only part of the way across the ocean, the received signals are weak and sometimes cease altogether. It would almost appear as if electric waves in passing from dark space to illuminated space, and vice versa, were reflected in such a manner as to be deviated from their normal path.

It is probable that these difficulties would not be experienced in telegraphing over equal distances north and south, on about the same meridian, as in this case the passage from daylight to darkness would occur almost simultaneously over the whole distance between the two points.

Another curious result, on which hundreds of observations continued for years leave no further doubt, is that regularly, for short periods, at sunrise and sunset, and occasionally at other times, a shorter wave can be detected across the Atlantic in preference to the longer wave normally employed.

Thus at Clifden and Glace Bay when sending on an ordinary coupled circuit arranged so as to simultaneously radiate two waves, one 12,500 feet and the other 14,700 feet, although the longer wave is the one usually received at the other side of the ocean, regularly, about three hours after sunset at Clifden, and three hours before sunrise at Glace Bay, the shorter wave alone was received with remarkable strength, for a period of about one hour.

This effect occurred so regularly that the operators tuned their receivers to the shorter wave at the times mentioned, as a matter of ordinary routine.

With regard to the utility of wireless telegraphy there is no doubt that its use has become a necessity for the safety of shipping, all the principal liners and warships being already equipped, its extension to less important ships being only a matter of time, in view of the assistance it has provided in cases of danger.

Its application is also increasing as a means of communicating between outlying islands, and also for the ordinary purposes of telegraphic communication between villages and towns, especially in the colonies and in newly developed countries.

However great may be the importance of wireless telegraphy to ships and shipping, I believe it is destined to an equal position of importance in furnishing efficient and economical communication between distant parts of the world and in connecting European countries with their colonies and with

America. As a matter of fact, I am at the present time erecting a very large power station for the Italian Government at Coltano, for the purpose of communicating with the Italian colonies in East Africa, and with South America.

Whatever may be its present shortcomings and defects, there can be no doubt that wireless telegraphy – even over great distances – has come to stay, and will not only stay, but continue to advance.

If it should become possible to transmit waves right round the world, it may be found that the electrical energy travelling round all parts of the globe may be made to concentrate at the antipodes of the sending station. In this way it may some day be possible for messages to be sent to such distant lands by means of a very small amount of electrical energy, and therefore at a correspondingly small expense.

But I am leaving the regions of fact, and entering the regions of speculation, which, however, with the knowledge we have gradually gained on the subject, promise results both useful and instructive.

Not having the fortune of being conversant with the Swedish language, I have thought it best, although an Italian, to use the medium of the English language in delivering this address, as I know that English is more generally understood here than Italian.

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2. *J. Inst. Elec. Engrs. (London)*, 28 (1899) 278.
3. See letter of Dr. Lodge in *The Times (London)*, June 22, 1897.
4. A. Slaby, *Die Funkentelegraphie*, Verlag von Leonhardt Simion, Berlin, 1897; see also A. Slaby, «The New Telegraphy», *The Century Magazine*, 55 (1898) 867.
5. *J. Inst. Elec. Engrs. (London)*, 28 (1899) 291.
6. *Brit. Patent* No. 12,326, June 1, 1898; *Brit. Patent* No. 6,982, April 1, 1899.
7. A. Blondel and G. Ferrie, «État actuel et Progrès de la Télégraphie sans Fil», read at the *Congrès International d'Électricité, Paris, 1900*; see also *J. Soc. Arts*, 49 (1901) 509.
8. *Brit. Patent* No. 7,777, April 26, 1900; see also *J. Soc. Arts*, 49 (1901) 510–11.
9. See Letter of Prof. J. A. Fleming in *The Times (London)*, October 4, 1900.
10. *Proc. Roy. Soc. (London)*, 72 (May 28, 1903).
11. J. A. Fleming, *The Principles of Electric Wave Telegraphy*, Longmans, Green & Co., London, 1906, p. 348.
12. J. Zenneck, *Ann. Physik*, [4], 23 (Sept. 1908) 846; *Physik. Z.*, 9 (1908) 50, 553.
13. *J. Soc. Arts*, 49 (1901) 512.
14. G. Marconi, lecture before the Royal Institution of Great Britain, June 13, 1902.

15. G. Marconi, «A Note on the Effect of Daylight upon the Propagation of Electromagnetic Impulses», *Proc. Roy. Soc. (London)*, 70 (June 12, 1902).
16. See also J. J. Thomson, «On Some Consequences, etc.», *Phil. Mag.*, [6] 4 (1902) 253.
17. See Ref. 11, p. 618.
18. *Riv. Marittima (Rome)*, October 1902.
19. G. Marconi, Paper read before the Royal Institution of Great Britain, March 3, 1905.
20. See also G. Marconi, Lecture before the Royal Institution of Great Britain, March 13, 1908.
21. G. Marconi, «On Methods whereby the Radiation of Electric Waves may be mainly confined, etc.», *Proc. Roy. Soc. (London)*, A 77 (1906).
22. G. Marconi, «Note on a Magnetic Detector of Electric Waves», *Proc. Roy. Soc. (London)*, 70 (1902) 341.

ELECTRICAL OSCILLATIONS AND WIRELESS TELEGRAPHY

Carl Ferdinand Braun

Carl Ferdinand Braun

Electrical oscillations and wireless telegraphy

Nobel Lecture, December 11, 1909

In accepting, today, the great honour and privilege of addressing the members of an Academy which though of venerable age is constantly renewed and invigorated by the contribution of fresh strength and energy, I hope for your indulgence and understanding when I conceive my task not to be that of talking about wireless telegraphy in general. I have felt it more fitting to limit myself to the narrower field of the activities in which I have been successful in taking some part in the development of the whole.

I shall ignore my experiments on the propagation of electrical waves through water which I carried out in the summer of 1898, and shall turn at once to the experiments which were described and conceived at that time as being transmission through the air.

The following should first be mentioned: Marconi, as far as I know, had begun his experiments on his father's estate in 1895, and continued them in England in 1896. His experiments in Spezia harbour were, with other ones, carried out in 1897, and a distance of 15 km was attained. In the autumn of the same year, Slaby, using much the same arrangement, reached 21 km over land but only by means of balloons to which were attached wires of 300 m in length. Why, must one ask, was it so difficult to increase the range? If the whole arrangement functioned satisfactorily over a distance of 15 km, why could not double and more the distance be attained by increasing the initial voltage, the means of doing which was available? It seemed, however, as if ever larger antennae were necessary. It was with this impression – whether the papers had correctly reported the experiments or not, I shall let pass – that I turned my attention to the subject in the autumn of 1898. I set myself the task of obtaining stronger effects from the transmitter.

If I am to give you the general thoughts and concepts which guided me I must ask you to carry yourselves back with me to the standpoint of our knowledge at that time. What facts were at our disposal and what conclusions could be drawn from them? It was known how sensitive the Hertzian oscillations were to the quality of the spark, and also that lengthening the spark led to definitely deleterious effects whereby the spark became « in-

active». Hertz had already, in his first work, called attention to the strong damping of the oscillators and compared their electrical oscillations with the ill-defined acoustic oscillations of wooden rods. Bjerknes, in 1891, had successfully measured the damping and found the logarithmic decrement (as well known the measure for damping) for a linear oscillator to be 0.26, when he used only a minute spark gap. When, however, the spark gap was increased to 5 mm, the decrement rose to 0.40. This, and a series of other facts, indicated the existence of strong spark damping. All known facts became understandable if one assumed that at low capacities the spark consumed a great part of the energy, and the longer the spark was, the larger was the part of energy it consumed. On the other hand, it had long been known that the discharge of bigger capacities in the customary arcs was always oscillatory, and (in radiation-free paths) was obviously much less attenuated. In fact Feddersen had already directly photographed up to 20 half-cycles of oscillations in 1862. I took hold of this fact.

Considering the greater amounts of energy which can be collected and stored in suitable experimental form in capacitors, one could expect to deliver radiated energy for some time from them. Taken all-in-all, I concluded that if a *sparkless* antenna could be excited, from a closed Leyden-jar circuit of large capacity, into potential oscillations whose average value was that

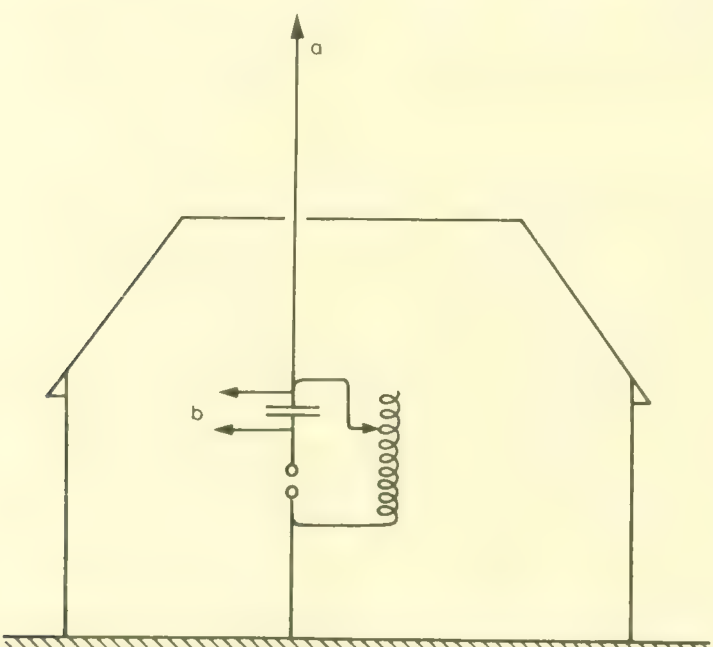


Fig. 1.

of the initial charge in a Marconi transmitter, then one would possess a more effective transmitter. There was some doubt as to whether this could be attained. And further, it was necessary to decide, by experiments on effects at a distance, whether any disturbing factor had been overlooked in these considerations. By suitable dimensioning of the exciter circuit it was found possible to fulfil the first requirement, and comparative experiments on long-distance effects were in favour of the new arrangement.

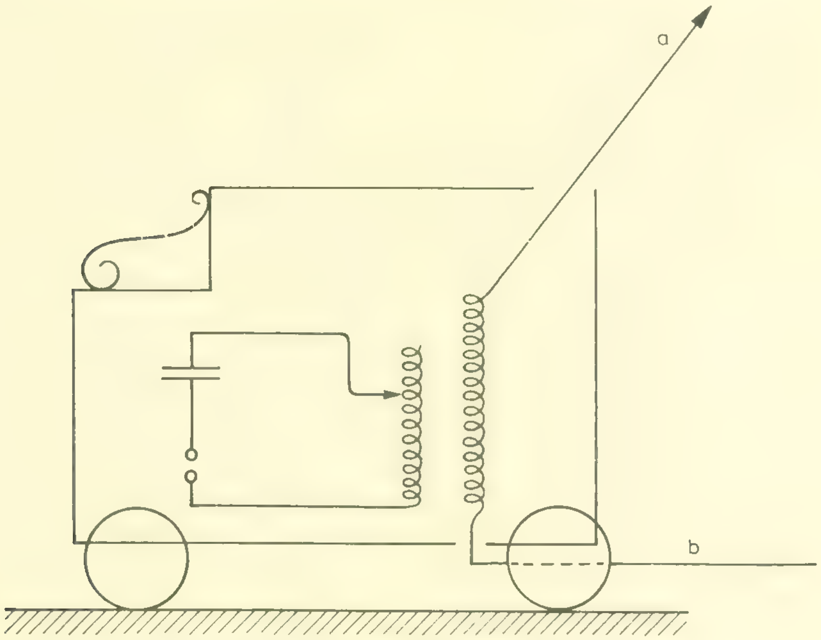


Fig. 2.

Three circuits arose from this, which I described as inductive and direct transmitter excitation, together with a mixed circuit derived from both. In Fig. 1 is shown the direct circuit. The transmitter is earthed. In Fig. 2 is shown the inductive circuit, in which Marconi's direct earthing is replaced by a « symmetry wire ». This name would be entirely suitable if the complete transmitter were floating in free space (e.g., in a balloon). The transmitter would then form a half-wavelength and the excitation point, which should lie at the antinode of the current, would be in the middle. Fig. 2 shows how this circuit is adapted to a mobile station. The set-up is now unsymmetrical due to the proximity of earth. The symmetry wire can be shortened by loading its end with capacity. This arrangement is then known as a counterpoise. It disappears entirely if the connected capacity is infinitely large, that is to say, when the excitation point is on well-conducting earth.

By a suitable design of the Leyden-jar circuit, significantly higher voltages are attained in the transmitter than the charging voltage of the Leyden-jar circuit. There was some suspicion in my mind that large capacities with bigger spark lengths would behave in the same way as small capacities. At that time, little was known about this. The results of later experiments have, in part, contradicted each other, since other losses appearing with high voltages were overlooked. But as far as the spark resistance was concerned my fears, as M. Wien has recently shown, were without foundation. Since I wanted, however, to be prepared for every eventuality, I asked myself whether it might not still be possible to increase the power, for instance by connecting *several* circuits of the *same* frequency of oscillation into the excitation circuit of the transmitter. The difficulty was to so couple circuits of this kind together that they would all start to discharge at the same moment, for example within exactly $\frac{1}{10}$ of a millionth of a second. This task occupied me on repeated occasions. One solution, attained in a somewhat different way and to which I was led in the course of my experiments, is given here (Fig. 3). It has been described as an « energy coupling ». I will touch later upon the advantages possessed by this arrangement, which remain despite the results obtained by Wien.

The experiments were to be carried further under practical conditions after Easter of 1899. The choice of location for the tests fell upon Cuxhaven. In addition to the main task there was an almost overwhelming pressure of

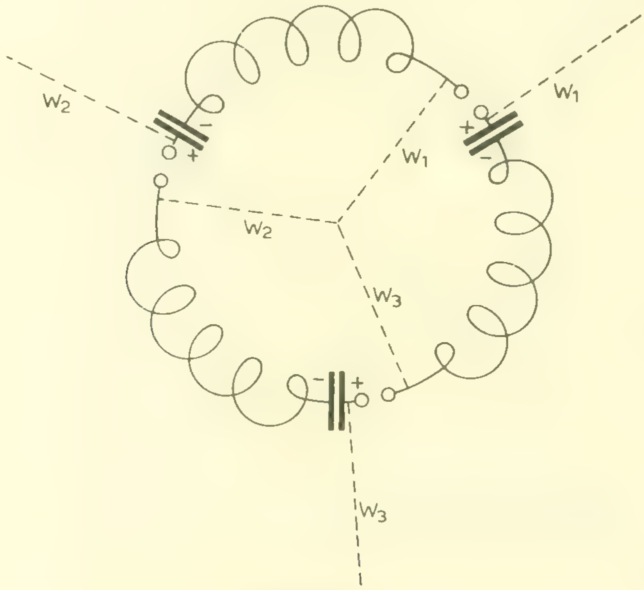


Fig. 3.

other allied tests and problems, e.g., how does the coherer work, particularly under the practical conditions occurring? Is it a resistance or does it behave like a capacitance or both? Can it be replaced by something better-defined, and if possible, more quantitatively informative? How do nearby buildings or metal masses such as masts and stays, which play such an important part in practice, affect the antenna? And there was a further multitude of problems with respect to the particular receiving apparatus. And all these problems affected the overall solution so that they all needed to be solved nearly simultaneously. Owing to my professional duties I could devote but little time to the tests, and they were carried on by two of my assistants until the autumn of 1900. The way in which the most favourable conditions were discovered in practice by systematic methods has been described by me elsewhere.

On November 16, 1900, I gave my first public lecture on this subject to the Natural Sciences Society in Strasbourg. There I described, among other matters, the advantages offered by my circuits for tuned telegraphy, advantages which Marconi had by then also recognized. On the following February 1, I demonstrated before the same Society the methods on which I had based the tuning of a receiver. I carried out more or less the same experiments before the Assembly of Research Workers in Natural Sciences in Hamburg during the autumn of the same year, as well as demonstrating the practical results on the station at Heligoland.

In the receiver, too, the most important feature was the capacitor circuit

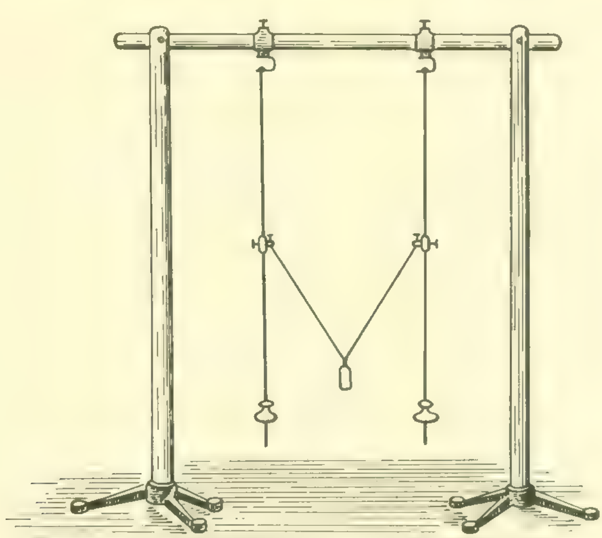


Fig. 4.

which was directly coupled to the antenna, and which, as I expressed it, collects the energy radiated towards the receiver into the best possible loss-free paths, localizes it and thus passes it onwards in the most suitable form for the detector.

By my arrangements, so-called *coupled* systems were introduced throughout in the wireless telegraphy system, and at this point we might briefly examine their properties. For preference I have used Oberbeck's pendulum model for illustration although it does not correspond completely to the electrical conditions. I produce it here (Fig. 4). Two pendulums of identical frequency are «coupled» through a loaded thread. I draw the first pendulum away from the position of rest and release it. It transmits its energy to the second pendulum and the latter increases its energy at the cost of the first, exciting pendulum. After some time the whole of the energy appears in the second pendulum. At this point, however, the process repeats itself in the opposite sequence. If I make the first pendulum heavy and the second one light, I can make the oscillation amplitude of the second greater than that of the first. The first pendulum represents the Leyden-jar circuit, the second the transmitter to which – in this case – the whole of the energy of the Leyden-jar circuit is passed. According to the ratio of the capacities the voltage can be amplified (or, if desired, reduced).

Now Oberbeck in 1895 demonstrated the following by calculation. If a capacitor circuit is allowed to operate inductively upon a second circuit of the *same* natural frequency there appear – most strikingly – *two* oscillations in both circuits, one higher and one lower than the natural frequency of oscillation. The closer the coupling, i.e., the quicker the energy transference from the first to the second circuit becomes the further apart lie the frequencies. Only for the case of infinitely loose coupling do the two oscillations approximate to the natural frequency, that is to say, become equal to each other.

This result holds also for mechanical systems, which includes our pendulums. If our two equally-tuned pendulums are coupled, then each should exhibit *two* different frequencies of oscillation. The result loses its surprise, when the phenomenon, I would like to say, is not treated mathematically but actually takes place before our eyes. The characteristic is this: the oscillations of the second pendulum increase steadily from zero upwards, then again decrease, and vice versa. We note from each pendulum what is known in acoustics as «beating». I shall recall now a method of representing graphically the acoustic beating (Fig. 5). An oscillating tuning fork carries a glass

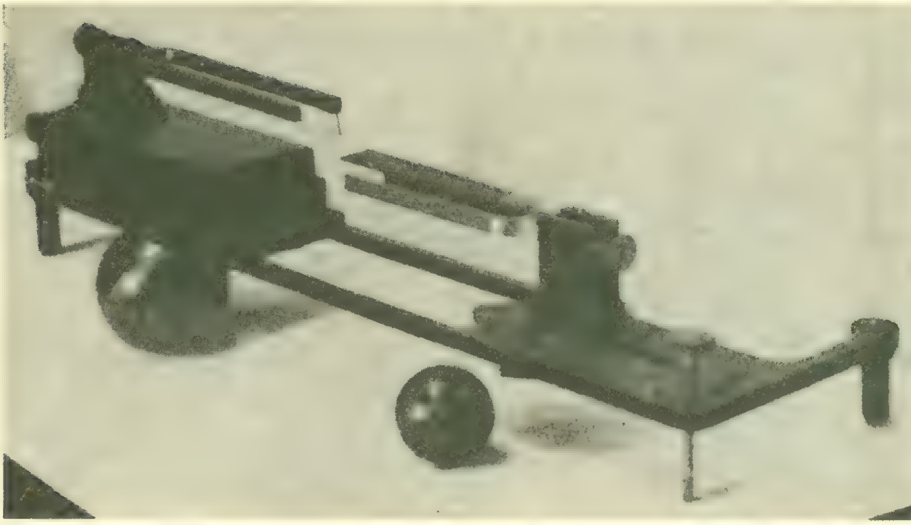


Fig. 5.

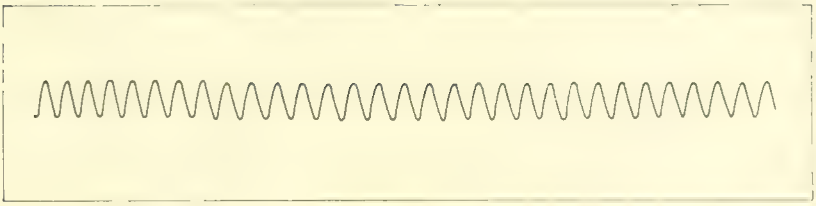


Fig. 6.

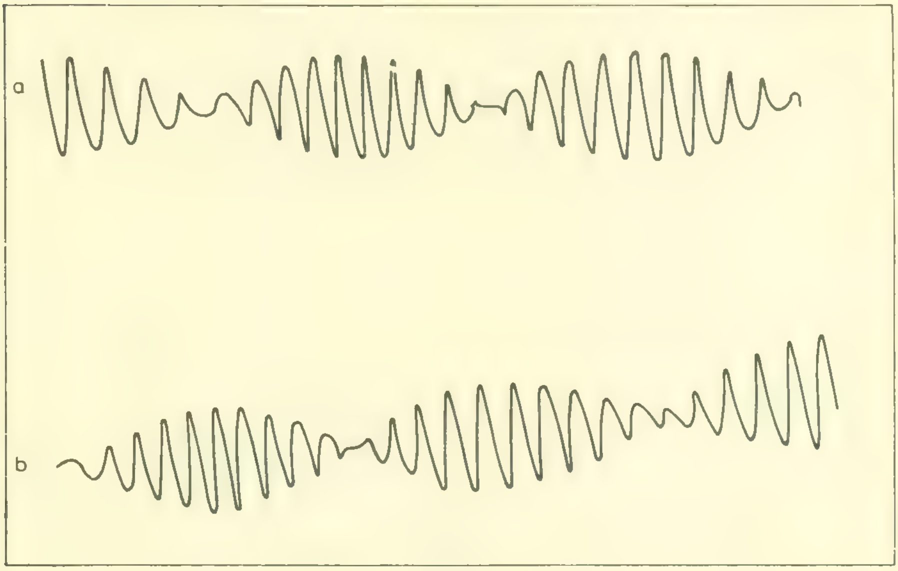


Fig. 7.

plate covered in soot (carbon black). A second tuning fork writes upon this oscillating glass plate by means of a small pin whilst it itself is drawn across the plate. *One* tuning fork would describe a curve of constant amplitude (Fig. 6). The oscillations of both forks are added algebraically. And when both forks have different frequencies, as is here the case, a curve as in Fig. 7 results.

I shall call them briefly «beating (or pulsating) oscillations». Just such curves would arise if we allowed our *pendulum* to write upon a moving plate. If the exciting pendulum gave the upper curve, *a*, then the excited pendulum would give the lower curve, *b*.

Each *such* beating oscillation can be considered – from the elementary laws of trigonometry – as arising from the superposition of two harmonic oscillations of different frequency, say n_1 and n_2.

Although this is mathematically possible, however, experience teaches us that if this pulsating oscillation is applied to a structure capable of oscillation whose natural frequency fits in with one or other of the frequencies n_1 or n_2, then it will be excited in its own natural frequency of oscillation. It selects one of the fictitious harmonic components and endows it thereby with an independent existence. A body so excited is called a resonator, and the phenomenon itself is known as resonance.

The thing is clear to the mind in the case of the tuning fork example. In space we would observe the beats, but resonators would separate the two tuning-fork tones. The application to our pendulum model is also obvious. Each part of the system performs pulsating oscillations, resonators react to two different harmonic oscillations.* If we wish (and here I return to the electrical example), to record, by means of resonators, oscillations from the radiation sent into space by the antenna, then we have to adjust the resonator to one of the two oscillations.

These electrical oscillations can be separated by means of a variable capacitor circuit, the so-called resonance Leyden-jar circuit (to which I will return later), *so long as care is taken* that as far as possible the circuit has no feed-back into the system being investigated. Oberbeck's result was concerned with the case where both system components had *closed* current circuits (with quasi-stationary flow) and were inductively coupled. It can now be easily

* If time allowed, I would be able to demonstrate both these oscillations «analytically» by means of the pendulum model. This second model, introduced by Dr. Mandelstam, and representing direct coupling through its correct mechanical analogue, allows every detail to be recognized.

shown that both oscillations also exist in the open current path of an antenna, whether it is excited directly or inductively (I am ignoring higher harmonics).

In the summer of 1902 I was able to erect two experimental stations on two forts at Strasbourg for the purpose of closer study. The task which I had set for us was to determine the most favourable conditions in the receiver. We adopted the resonant circuit, in which known capacitances were combined with calculated self-inductances, so as to bring both parts of the transmitter system into the same natural frequency of oscillation. We fixed likewise the two oscillations arising from the coupling and searched for these with the receiver. The result of the test was, for that time, surprising, as an example will show. If, by means of a coil in the receiver circuit, the oscillations were transferred inductively into a second coil located in a tuned circuit containing the indicator (parallel to a small capacitor), not only was the sharpness of the resonance but also – and here was the surprise – the *intensity* of the excitation was raised as soon as the two coils were *moved away* from one another. The intensity increased with increasing distance between the coils, though naturally beyond a certain limit there was again a decrease. Described in the customary expression, the effectiveness increased with *looser* coupling. This result in the receiver was *not* subject to a similar loose coupling in the transmitter.

There were two important results from these experiments: (*a*) greater freedom from disturbance in the receiver; and (*b*) a valuable measuring instrument for wireless engineering. When Dr. Franke of Siemens & Halske (who were working with us) saw the tests he proposed to base technically-useable equipment on them. Until then the resonance circuit had been assembled from existing parts to suit the particular requirements, and from whatever came to hand. Through the combination of a Köpsel's calibrated variable rotating capacitor and a number of calculated self-inductances, an apparatus was constructed which covered a large range of wavelengths both conveniently and continuously. The « current effect » was measured by means of a Riess's air thermometer which I had long used for intensity measurements of oscillations. The technical preparation fell to Mr. Dönitz. So arose the wave-meter, described by him and generally named after him, an apparatus which, using the theory already developed by Bjerknes in 1891, permitted simultaneously the *damping* or attenuation of electrical waves to be measured, a quantity whose numerical value was ever more needed. There are other wave-meters with open current paths; these are simpler, but despite this the closed-circuit apparatus has because of its other advantages held the field.

By means of this instrument the foundation of measuring techniques for wireless telegraphy were laid. It soon displaced our cumbersome laboratory equipment and gave us great help in our scientific investigations, whilst it became indispensible for rational technical work in the field of electrical oscillations.

In the summer of 1902 came the publication of a theoretical study of the coupled transmitter by Max Wien. This particularly concerned the effect of damping. Wien showed by calculation the versatility of the coupled transmitter. He summed up the qualitative results of his work as follows: « According to the kind of coupling, a powerful but quickly attenuated excitation can be attained which reaches far into the distance, or alternatively a slowly decreasing wave-train which is capable of exciting a similarly-tuned resonator while passing all others by – a cannon shot to be heard afar, or a soft, slowly declining tuning-fork tone »[4].

This theoretical investigation was most effective in clarifying the problem basically, and it will remain the foundation. It remains to be seen, however, how closely the data chosen for the numerical examples correspond to actual practice. Some calculated figures and a few laboratory figures were all that were available on the subject of damping. The field of measurements in relation to practice was beginning to be opened up. From then on, the work spread further and further outwards, branching into that of the scientific laboratories on the one hand, and the conversion of their results into practice with its complicated conditions and extensive requirements on the other. Success in the latter connection is due to Count Arco and Mr. Rendahl.

The circumstances which led me, more than ten years ago, to introduce the capacitor circuit, have altered greatly in the meantime. The Leyden-jar circuit is still to-day indispensible in wireless telegraphy. Two properties should be mentioned which I have not yet touched upon:

(1) For equal powers it is easier to design an inductor for use with high charging capacities and low voltages than vice versa. This was a determining factor at the time for the energy circuit mentioned earlier and remained so for this set-up.

(2) Insulation difficulties are practically non-existent in the Leyden-jar circuit, but the contrary is the case in the antenna circuit. If, for example, the insulators in a coupled transmitter are damp, the transmitter still works, whilst it can become impossible to charge it statically or with low frequency.

I illustrated the latter point in my lecture in November of 1900 by means of the following experiment. I allowed the transmitter to operate inductively upon a neighbouring receiver and so produced current in the latter which

brightly lit up an incandescent bulb. I touched the transmitter wire with a moist binding thread which was connected to earth. This had no effect on the operation in the case of the coupled transmitter, but the transmitter with direct inductor charging could not be operated once the damp thread was placed in contact with it.

Before I leave the subject of the coupled system I might perhaps recall an accessory which was of great use to me and other experimenters. I mean the cathode-ray tube which I described in 1897. It provided a visual picture of current- and voltage-waveforms up to 100 kc/s, and was the means by which investigations of period, waveform, intensity and thereby damping, as well as relative phases, could be made.

One of the first applications of this tube was Knut Ångström's neat method of showing directly the hysteresis curve. In a similar way, the permeability of iron up to 130 kc/s was investigated at the Strasbourg Institute, and a number of other problems concerned with electrical oscillations were also studied.

Three oscillograms made with the tube will serve to show its application. They illustrate the primary current pattern in the inductor, which interests us, and the significance of the capacitor therein.

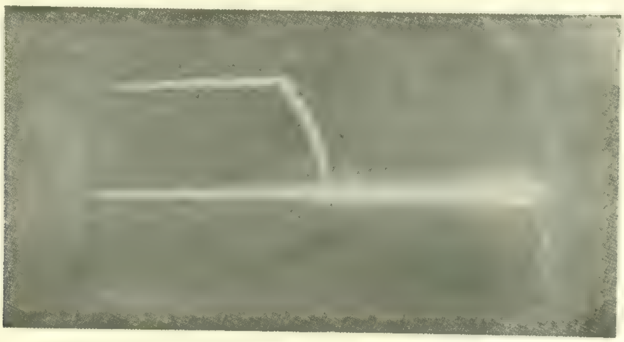


Fig. 8.

In Fig. 8 the primary current in the non-capacitative circuit falls away relatively slowly when the circuit is broken. On the other hand, if a capacitor (Fig. 9) is switched in, *oscillations* occur on breaking the circuit. The current falls much more steeply and by nearly twice the value. The secondary coil was open. If this coil circuit is closed (Fig. 10), the oscillations are faster and are attenuated more strongly.

Many applications of the tube are given in Zenneck's well-known book.

I will show you now only the current oscillations in two coupled (but strongly damped) capacitor circuits. You will see that the tubes do in fact show actual beating or pulsating oscillations (Fig. 11).

In still another place, wireless telegraphy brought me into contact with earlier investigations which I had made, this time in connection with work in my youth. I found in 1874 that materials such as galena, pyrite, pyrolusite,

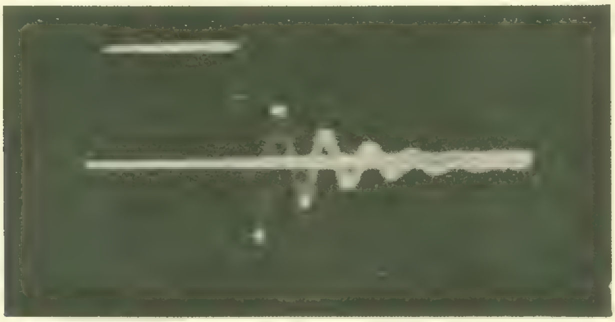


Fig. 9.

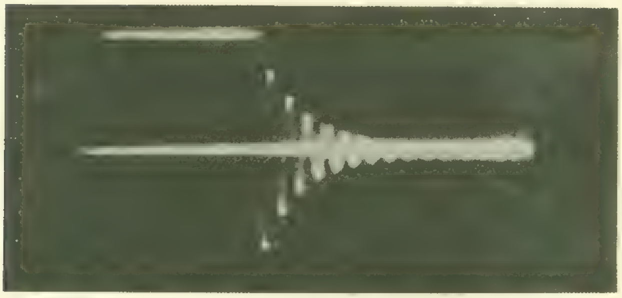


Fig. 10.

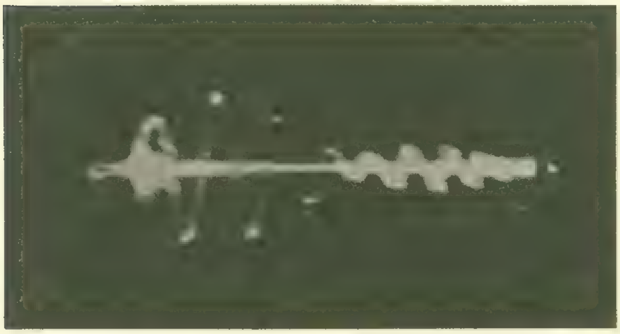


Fig. 11.

tetrahedrite, etc., departed from Ohm's Law, particularly when an electrode made contact over a small surface area. These materials greatly interested me since they conduct without electrolysis although they are binary compounds. The resistance appeared to be dependent upon the direction and intensity of the current and I could, for instance, separate the opening and closing currents of a small inductor by means of such materials, in a similar way to that of a Geisler's tube. I did not succeed in finding an « explanation » for the phenomena, for instance to what material unsymmetry the electrical unsymmetries (which without doubt existed) corresponded. I had to content myself with showing that the observed phenomena were not brought about through secondary effects such as heating. I was able to demonstrate that it appeared – at least qualitatively – even in 1/500 second, and I was convinced that – perhaps at the furthest limits – an inertialess process was concerned, a view which was supported by E. Cohn whilst carrying out some other experiments, when he found that the unsymmetrical d.c. resistance could follow current oscillations of 25 kc/s. But always there remained with me a feeling of dissatisfaction, and with it, a faint memory which had obviously never died, but remained half-somnolent at the back of my mind. Instinctively I was driven back to this valve effect (with which I had repeatedly, though in vain, attempted to obtain direct current from oscillations of light) when I began to occupy myself with wireless telegraphy in 1898. The elements showed the expected detector effect, but *at that time* offered no advantages over the coherer. As the swing to aural reception of messages took place, I came back to these materials, and recognized their usefulness for this purpose in 1901. In 1905 the *Gesellschaft für drahtlose Telegraphie* (Wireless Telegraphy Co.) decided, on my recommendation, to start up a technical project in this sphere of activity. Today, these detectors – including other combinations of a similar nature – are extensively used. Pierce, by means of the cathode-ray tube, has demonstrated for slow oscillations an almost complete separation of positive and negative current components in the case of molybdenite. It seems to me that it is still an open question whether this will hold also for rapid oscillations.

I will turn now to another series of experiments.

It had always seemed most desirable to me to transmit the waves, in the main, in one direction only. I will not concern myself with the successful experiments of this kind made at the Strasbourg Forts in 1901, since it came out later that similar proposals had already been made by others.

I found in 1902 that an antenna, inclined at somewhat less than 10° to the horizon, formed a kind of directional receiver. The receptivity showed a clearly defined maximum for waves passing through the vertical plane in which the antenna was situated. The results were published in March of 1903.

A directional *transmitter* is made up in the following way (Fig. 12). It is assumed that the antennae A and B, located at corners of an equilateral triangle, are equal in phase, but are *delayed* by a quarter of a cycle of oscillation relative to antenna C, which is in the third corner. The height CD of the triangle is to be a quarter wavelength. The radiation will then prefer the direction CD. The wave emanating from C will reach AB at the moment that A and B start to oscillate.

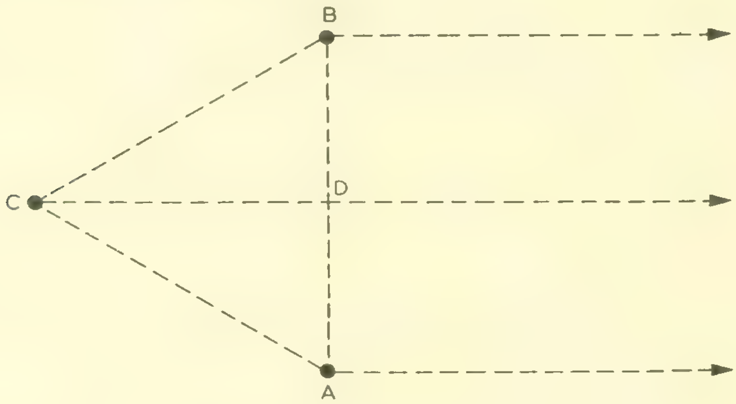


Fig. 12.

The task arose to attain this kind of phase difference for rapid oscillations, and prior to this, to measure such differences. A measuring method came easily to hand, one which has also proved itself in practical experiments. The solution of the other task did not go well using the scheme which I had thought out. On the other hand, two of my assistants found an ingenious solution when they took up the work, at my suggestion, in the Strasbourg Institute. Experiments were carried out on a big parade-ground in the vicinity of Strasbourg (spring of 1905).

In Fig. 13 is shown, schematically, the layout used. The field was measured at a fair distance away, that is to say, in the so-called wave-zone. There was satisfactory agreement between theory and observation, and the results were checked in various ways. It was further shown that the experimental layout functioned in the desired sense. By suitable distribution of the amplitudes in the three transmitters, a field as in Fig. 14 was calculated (the

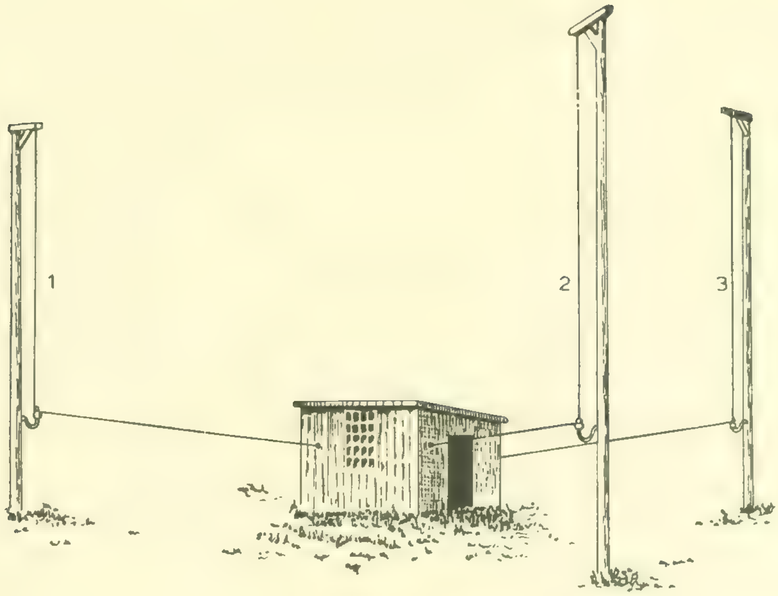


Fig. 13.

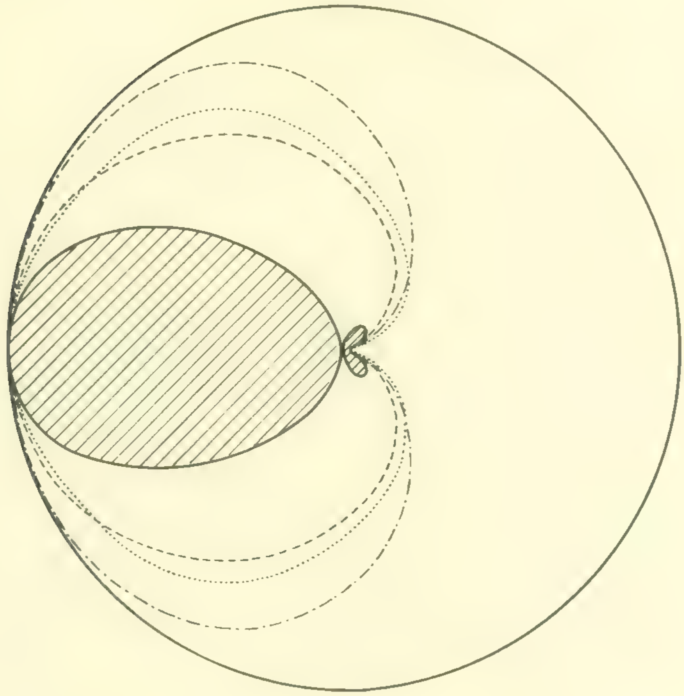


Fig. 14.

singly dotted curve is the measured field). The radial vectors represent the range. If the roles of the three transmitters are exchanged – by simply tripping a change-over switch – the preferred direction can be rotated through 120° or 60°.

It would appear to be of general interest to remark that one is led to the conclusion that the radiation of a transmitter is reduced here by the oscillations in its neighbour, which are shifted in position and phase, a conclusion which could be proved experimentally.

If nowadays optical phenomena are ascribed to electrical molecular resonators, then electrical processes, as demonstrated here by a single example, can also be linked up with optical phenomena, though this can hardly be experimentally verified in this field.

Here, the study of electrical oscillations supplements that of optical oscillations, and since we are in the position to tackle a problem in either field by analogy with a phenomenon which is comprehended in the other field, the first attack on the problem can be made from the electrical or the optical standpoint according to whichever presents the easier concept to realize. I can perhaps illustrate this by means of two worked-out examples.

Elementary considerations led me to the conclusion that a medium, composed of layers of different dielectric constants, must behave as a uniaxial crystal if it is assumed that the layer thicknesses are only a fraction of a wavelength. I was able to confirm this conclusion in the following way (Fig. 15). A beam of practically parallel electrical rays emerges from the Hertzian reflector. It strikes a structure made of bricks in layers having the same breadth of air layers. These layers lie open to short waves, but if the wavelength is 12 times, or so, longer than the layer thickness, then the brick grating behaves towards it as a body which *homogeneously* occupies the space but exhibits double refraction. The electrical oscillations are linearly polarized and incident at an azimuth of 45° upon the brick layers. A brick structure which is

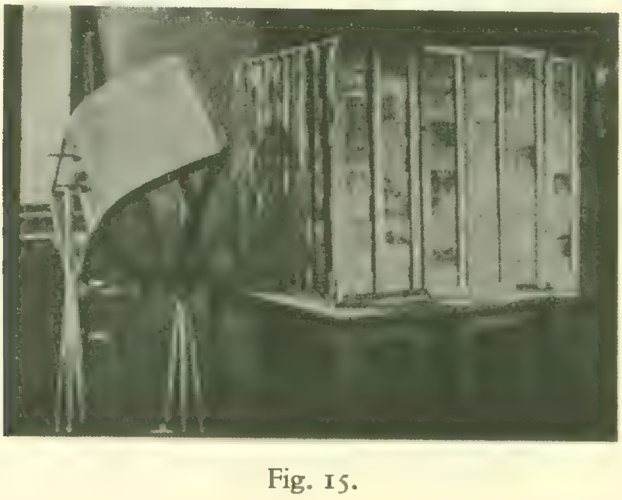


Fig. 15.

about $2\frac{1}{2}$ times the thickness of a single brick has the effect of a quarter-wave foil of mica, and the linearly-incident ray emerges circularly polarized as we deduce from the investigations with a Righi's resonator. Assume it is right-handed circular. If the layer thickness is now doubled, the emergent wave is again linearly polarized, though in the other quadrant. And so we can transform the ray, by continuous addition of further thicknesses, into a left-handed circular one, and finally back into a ray which is linearly polarized parallel to the incident ray. The double refraction of the brick grating surpasses that of calcite. Optically, this brick structure would correspond to a tiny crystal of a few thousandths of a millimetre length of edge, but electrically it is $2\frac{1}{2}$ metres thick, weighs 4000 kg, and its raw material is worth about 200 marks. The analogue of a corresponding optical phenomenon was also demonstrated by me at a later date.

This phenomenon of double refraction does not depend upon the use of rigid materials. Whether the double refraction occurring in cross-striated muscle results from a similar layer structure is thus a closely related question.

We have so far studied an electrically unknown, but optically conjectured phenomenon and both have been discovered to exist. The following example is concerned with demonstrating the unknown optical phenomenon corresponding to a known electrical phenomenon. It seemed to me to be of interest to reproduce the Hertzian grid experiment in the field of visible rays. For this to be realized, a very fine grating of metal wires was necessary and from 10,000 to 100,000 tiny wires, separated by air gaps, had to be located within a width of 1 mm. Mechanical methods of manufacture are impossible, but a Hertzian grid could be made in the following way. If a powerful discharge is passed through a thin metal wire on a glass plate, or between two such plates, the well-known sputtering or vaporization effect occurs, as you can see from Fig.16. The metal wire vaporizes (temperatures of up to 30,000°

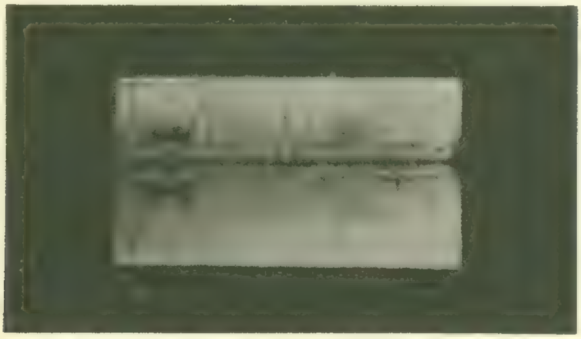


Fig. 16.

are calculated). The metal vapour is driven outwards by the pressure arising from the explosive effect (Fig. 17) and is then again precipitated obviously in a kind of grid structure on the glass. If we allow linearly polarized light to fall upon the prepared surface, it will, if the oscillations are parallel to the lines of the grid, be strongly reflected and strongly absorbed – the preparation appears dark (Fig. 18). If the plane of the oscillations is turned so that it is perpendicular to the lines of the grid, the metal layer becomes transparent

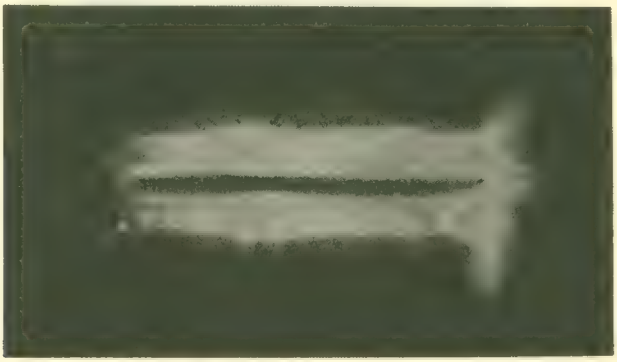


Fig. 17.

Fig. 18.

(Fig. 19). We have the complete optical analogue to a Hertzian grid made out of moderately good conductors.

This experiment permits a further development. If we imagine that in an organized fabric such as muscle tissue, plant fibres, etc. there exists a similar fine grating structure somewhat in the form of the finest possible channels, then if we could succeed in filling these with metal, the preparation would have the optical effect of a Hertzian grid. H. Ambronn, in 1896, treating the

Fig. 19.

above mentioned substances with gold or silver salts, discovered phenomena which I explained in this way. In an exhaustive investigation into this matter I have everywhere found confirmation of my concept, and nowhere a contradiction. Yet a direct and incontrovertible proof would be extremely desirable because of the importance of its consequences. For if my idea is, as I believe, correct, then we would in this way not only discover sub-microscopic gratings, but, as a result of electrical imitation, we would even be able to some extent to make a picture of the material structure which is as yet invisible to the human eye. This method would augment those so far available in a most valuable manner, for it takes its place just where the microscope and – because of the density of the particles – even the ultramicroscope, reach the limit of their capacity.

I must now finish this address. The sputtering experiments led me back to the Leyden-jar circuit. I pursued for a long time the aim of automatically switching out the Leyden-jar circuit from the oscillating system as soon as it had given up its energy to the secondary conductor. I attempted this in the following way. A thin wire was connected into the Leyden-jar circuit, and I hoped that, at the right moment, the primary circuit would be switched out as a result of vaporization of the wire. The experiment was not successful, at any rate at the frequencies which I used, apparently because the highly heated metal vapour remained ionized for too long a time. The problem was solved, however, by Max Wien using the so-called quenched spark, and by Rendahl using the mercury spark-gap. Practical experience has augmented

Wien's discovery. Arising from this and through the agency of Rendahl and Arco, came the so-called tone-spark. The small hissing or quenched sparks of Wien of itself meet the conditions which I had hoped to produce artificially. The Leyden-jar circuit cuts itself out at the most suitable moment, and the greater part of the primary energy then oscillates in the highly conductive paths in the transmitter at its own natural frequency.

On the occasion of my first lecture in November 1900 I closed with the following words:

« Sometimes, wireless telegraphy has been described as spark telegraphy, and so far a spark in one place or another has been unavoidable. Here, however, it has been made as harmless as possible. This is *important*. For the spark which produces the waves also destroys them again as Saturn destroyed his own children. What was pursued here could be truthfully described as *sparkless telegraphy*. »

Finishing as I did with these words at that time, I feel happy to think that with the means I have described we have come appreciably nearer to this target, and have thereby made the coupled transmitter still more effective.

RADIOTELEGRAPHY

G[uglielmo] Marconi

RADIOTELEGRAPHY.[1]

[With 1 plate.]

By Commendatore G. Marconi, LL.D., D.Sc.

The practical application of electric waves to the purposes of wireless telegraphic transmission over long distances has continued to extend to a remarkable degree during the last few years, and many of the difficulties, which at the outset appeared almost insurmountable, have been gradually overcome, chiefly through the improved knowledge which we have obtained in regard to the subject generally and to the principles involved.

The experiments which I have been fortunate enough to be able to carry out, on a much larger scale than can be done in ordinary laboratories, have made possible the investigation of phenomena often novel and certainly unexpected.

Although we have—or believe we have—all the data necessary for the satisfactory production and reception of electric waves, we are yet far from possessing any very exact knowledge concerning the conditions governing the transmission of these waves through space, especially over what may be termed long distances. Although it is now perfectly easy to design, construct, and operate stations capable of satisfactory commercial working over distances up to 2,500 miles, no really clear explanation has yet been given of many absolutely authenticated facts concerning these waves. Some of these hitherto apparent anomalies I shall mention briefly in passing.

Why is it that when using short waves the distances covered at night are usually enormously greater than those traversed in the day time, while when using much longer waves the range of transmission by day and night is about equal and sometimes even greater by day?

What explanation has been given of the fact that the night distances obtainable in a north-southerly direction are so much greater than those which can be effected in an east-westerly one?

Why is it that mountains and land generally should greatly obstruct the propagation of short waves when sunlight is present and not during the hours of darkness?

[1] Reprinted by permission from author's separate of Proceedings of the Royal Institution. Read before Royal Institution of Great Britain at weekly evening meeting, Friday, June 2, 1911.

The general principles on which practical radiotelegraphy is based are now so well known that I need only refer to them in the briefest possible manner.

Wireless telegraphy, which was made possible by the fields of research thrown open by the work of Faraday, Maxwell, and Hertz, is operated by electric waves, which are created by alternating currents of very high frequency, induced in suitably placed elevated wires or capacity areas. These waves are received or picked up at a distant station on other elevated conductors tuned to the period of the waves, and the latter are revealed to our senses by means of appropriate detectors.

My original system as used in 1896 consisted of the arrangement shown diagrammatically in figure 1, where an elevated or vertical wire was employed. This wire sometimes terminated in a capacity or was connected to earth through a spark gap.

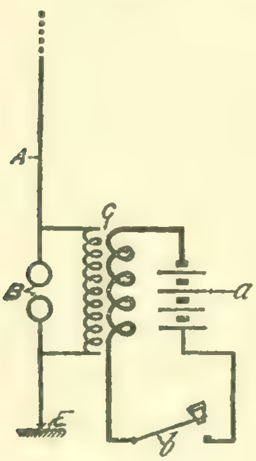


FIG. 1.

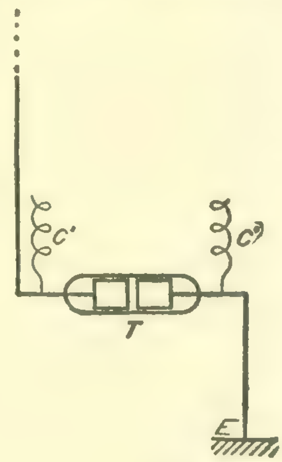


FIG. 2.

By using an induction coil or other source of sufficiently high tension electricity sparks were made to jump across the gap; this gave rise to oscillations of high frequency in the elevated conductor and earth, with the result that energy in the form of electric waves was radiated through space.

At the receiving station (fig. 2) these waves induced oscillatory currents in a conductor containing a detector, in the form of a coherer, which was usually placed between the elevated conductor and earth.

Although this arrangement was extraordinarily efficient in regard to the radiation of electrical energy, it had numerous drawbacks.

The electrical capacity of the system was very small, with the result that the small amount of energy in the aerial was thrown into space in an exceedingly short period of time. In other words, the energy, instead of giving rise to a train of waves, was all dissipated after only a few oscillations, and, consequently, anything approaching good tuning between the transmitter and receiver was found to be unobtainable in practice.

Many mechanical analogies could be quoted which show that in order to obtain syntony the operating energy must be supplied in the form of a sufficient number of small oscillations or impulses properly timed. Acoustics furnish us with numerous examples of this fact, such as the resonance produced by the well-known tuning fork experiment.

Other illustrations of this principle may be given; e. g., if we have to set a heavy pendulum in motion by means of small thrusts or impulses, the latter must be timed to the period of the pendulum, as otherwise its oscillations would not acquire any appreciable amplitude.

In 1900 I first adopted the arrangement which is now in general use, and which consists (as shown in fig. 3) of the inductive association of the elevated radiating wire with a condenser circuit which may be used to store up a considerable amount of electrical energy and impart it at a slow rate to the radiating wire.

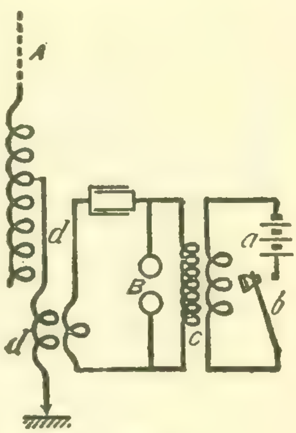


Fig. 3.

As is now well known, the oscillations in a condenser circuit can be made to persist for what is electrically a long period of time, and it can be arranged moreover that by means of suitable aerials or antennæ these oscillations are radiated into space in the form of a series of waves, which through their cumulative effect are eminently suitable for enabling good tuning and syntony to be obtained between the transmitter and receiver.

The circuits, consisting of the condenser circuit and the elevated aerial or radiating circuit, were more or less closely coupled to each other. By adjusting the inductance in the elevated conductor, and by the employment of the right value of capacity or inductance required in the condenser circuit, the two circuits were brought into electrical resonance, a condition which I first pointed out as being essential in order to obtain efficient radiation and good tuning.

The receiver (as shown in fig. 4) also consists of an elevated conductor or aerial connected to earth or capacity through an oscillating transformer. The latter also contains the condenser and detector, the circuits being made to have approximately the same electrical time period as that of the transmitter circuits.

At the long distance station situated at Clifden, in Ireland, the arrangement which has given the best results is based substantially upon my syntonic system of 1900, to which have been added numerous improvements.

An important innovation from a practical point of view was the adoption at Clifden and Glace Bay of air condensers, composed of insulated metallic plates suspended in air at ordinary pressure. In this manner we greatly reduce the loss of energy which would take place in consequence of dielectric hysteresis were a glass or solid dielectric employed. A very considerable economy in working also results from the absence of dielectric breakages, for, should the potential be so raised as to even produce a discharge from plate to plate across the condenser, this does not permanently affect the value of the dielectric, as air is self-healing and one of the few commodities which can be replaced at a minimum of cost.

Various arrangements have been tried and tested for obtaining continuous or very prolonged trains of waves, but it has been my experience that, when utilizing the best receivers at present available, it is neither economical nor efficient to attempt to make the waves too continuous. Much better results are obtained when groups of waves (fig. 5) are emitted at regular intervals in such manner that their cumulative effect produces a clear musical note in the receiver, which is tuned not only to the periodicity of the electric waves transmitted but also to their group frequency.

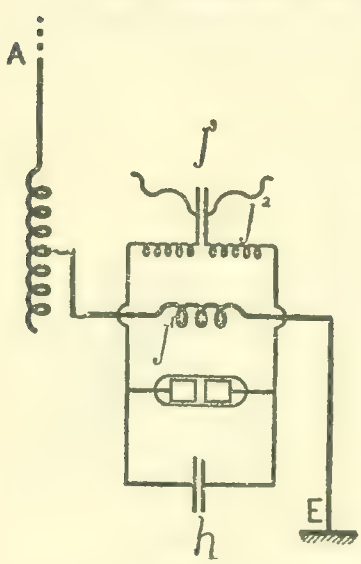


FIG. 4.

In this manner the receiver may be doubly tuned, with the result that a far greater selectivity can be obtained than by the employment of wave tuning alone.

In fact, it is quite easy to pick up simultaneously different messages transmitted on the same wave length, but syntonized to different group frequencies.

As far as wave tuning goes, very good results—almost as good as are obtainable by means of continuous oscillations—can be achieved with groups of waves, the decrement of which is in each group 0.03 or 0.04, which means that about 30 or 40 useful oscillations are radiated before their amplitude has become too small to perceptibly affect the receiver.

The condenser circuit at Clifden has a decrement of from 0.015 to 0.03 for fairly long waves.

This persistency of the oscillations has been obtained by the employment of the system shown in figure 6, which I first described in a patent taken out in September, 1907. This method eliminates

almost completely the spark gap and its consequent resistance, which, as is well known, is the principal cause of the damping or decay of the waves in the usual transmitting circuit.

The apparatus shown in figure 6 consists of a metal disk *a*, having copper studs firmly fixed at regular intervals in its periphery and placed transversely to its plane. This disk is caused to rotate very rapidly between two other disks, *b*, by means of a rapidly revolving electric motor or steam turbine. These side disks are also made to slowly turn round in a plane at right angles to that of the middle disk. The connections are as illustrated in the figure. The studs are of such length as to just touch the side disks in passing, and thereby bridge the gap between the latter.

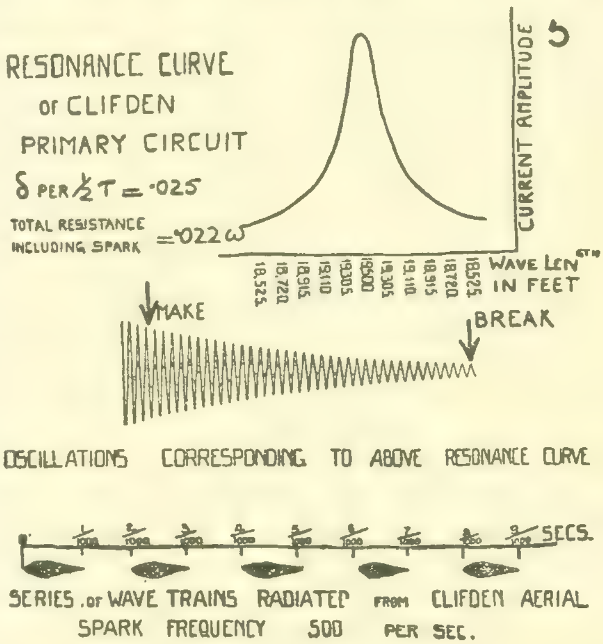


Fig. 5.

With the frequency employed at Clifden, namely, 45,000, when a potential of 15,000 volts is used on the condenser, the spark gap is practically closed during the time in which one complete oscillation only is taking place, when the peripherical speed of the disk is about 600 feet a second. The result is that the primary circuit can continue oscillating without material loss by resistance in the spark gap. Of course the number of oscillations which can take place is governed by the breadth or thickness of the side disks, the primary circuit being abruptly opened as soon as the studs attached to the middle disk leave the side disks.

This sudden opening of the primary circuit tends to immediately quench any oscillations which may still persist in the condenser circuit; and this fact carries with it a further and not inconsiderable advantage, for if the coupling of the condenser circuit to the aerial is of a suitable value the energy of the primary will have practically all passed to the aerial circuit during the period of time in which the

primary condenser circuit is closed by the stud filling the gap between the side disks; but after this the opening of the gap at the disks prevents the energy returning to the condenser circuit from the aerial, as would happen were the ordinary spark gap employed. In this manner the usual reaction which would take place between the aerial and the condenser circuit can be obviated, with the result that with this type of discharger and with a suitable degree of coupling the energy is radiated from the aerial in the form of a pure wave, the loss from the spark gap resistance being reduced to a minimum.

I am able to show a resonance curve taken at Clifden which was obtained from the oscillations in the primary alone (fig. 5).

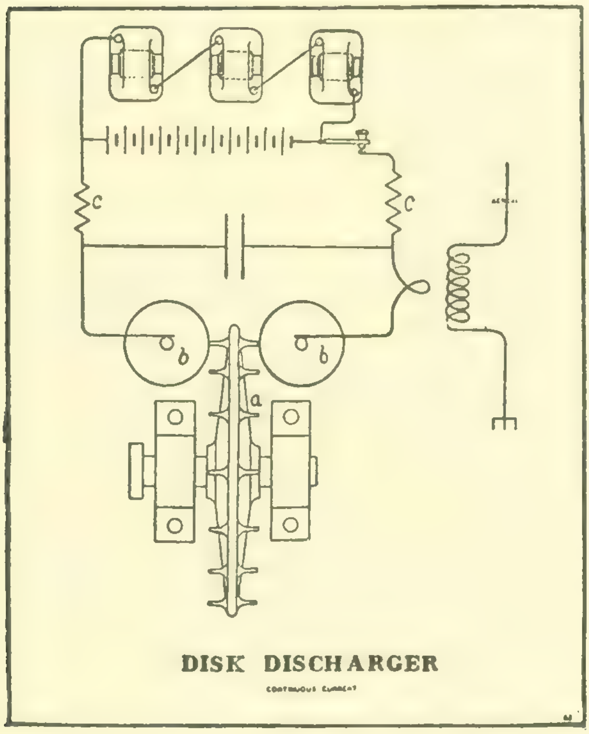


Fig. 6.

An interesting feature of the Clifden plant, especially from a practical and engineering point of view, is the regular employment of high-tension direct current for charging the condenser. Continuous current at a potential which is capable of being raised to 20,000 volts is obtained by means of special direct-current generators; these machines charge a storage battery consisting of 6,000 cells, all connected in series, and it may be pointed out that this battery is the largest of its kind in existence. The capacity of each cell is 40 ampere-hours. When employing the cells alone the working voltage is from 11,000 to 12,000 volts, and when both the direct-current generators and the battery are used together the potential may be raised to 15,000 volts through utilizing the gassing voltage of the storage cells.

For a considerable portion of the day the storage battery alone is employed, with a result that for 16 hours out of the 24 no running

machinery need be used for operating the station, with the single exception of the small motor revolving the disk.

The potential to which the condenser is charged reaches 18,000 volts when that of the battery or generators is 12,000. This potential is obtained in consequence of the rise of potential at the condenser plates, brought about by the rush of current through the choking or inductance coils at each charge. These coils are placed between the battery or generator and the condenser *c*, figure 6.

No practical difficulty has been encountered either at Clifden or Glace Bay in regard to the insulation and maintenance of these high-tension storage batteries. Satisfactory insulation has been obtained by dividing the battery into small sets of cells placed on separate stands. These stands are suspended on insulators attached to girders fixed in the ceiling of the battery room. A system of switches, which can all be operated electrically and simultaneously, divides the battery into sections, the potential of each section being low enough to enable the cells to be handled without inconvenience or risk.

The arrangement of aerial adopted at Clifden and Glace Bay is shown in figure 7. This system, which is based on the result of tests which I first described before the Royal Society in June, 1906,[1] not only makes it possible to efficiently radiate and receive waves of any desired length, but it also tends to confine the main portion of the radiation to any desired direction. The limitation of transmission to one direction is not very sharply defined, but nevertheless the results obtained are exceedingly useful for practical working.

FIG. 7.

In a similar manner, by means of these horizontal wires, it is possible to define the bearing or direction of a sending station, and also limit the receptivity of the receiver to waves arriving from a given direction.

The commercial working of radiotelegraphy and the widespread application of the system on shore and afloat in nearly all parts of the world has greatly facilitated the marshaling of facts and the observation of effects. Many of these, as I have already stated, still await a satisfactory explanation.

A curious result which I first noticed over nine years ago in long-distance tests carried out on the steamship *Philadelphia*, and which still remains an important feature in long-distance space telegraphy,

[1] "On methods whereby the radiation of electric waves may be mainly confined, etc." Proc. Roy. Soc., A, vol. 77, p. 413.

is the detrimental effect produced by daylight on the propagation of electric waves over great distances.

The generally accepted hypothesis of the cause of this absorption of electric waves in sunlight is founded on the belief that the absorption is due to the ionization of the gaseous molecules of the air affected by the ultra violet light, and as the ultra violet rays which emanate from the sun are largely absorbed in the upper atmosphere of the earth, it is probable that that portion of the earth's atmosphere which is facing the sun will contain more ions or electrons than that which is in darkness, and therefore, as Sir J. J. Thomson has shown,[1] this illuminated or ionized air will absorb some of the energy of the electric waves.

The wave length of the oscillations employed has much to do with this interesting phenomenon, long waves being subject to the effect of daylight to a very much lesser degree than are short waves.

Although certain physicists thought some years ago that the daylight effect should be more marked on long waves than on short, the reverse has been my experience; indeed, in some transatlantic experiments, in which waves about 8,000 meters long were used, the energy received by day at the distant receiving station was usually greater than that obtained at night.

Recent observation, however, reveals the interesting fact that the effects vary greatly with the direction in which transmission is taking place, the results obtained when transmitting in a northerly and southerly direction being often altogether different from those observed in the easterly and westerly one.

Research in regard to the changes in the strength of the received radiations which are employed for telegraphy across the Atlantic has been recently greatly facilitated by the use of sensitive galvanometers, by means of which the strength of the receiv^d signals can be measured with a fair degree of accuracy.

In regard to moderate power stations such as are employed on ships, and which, in compliance with the international convention, use wave lengths of 300 and 600 meters, the distance over which communication can be effected during daytime is generally about the same, whatever the bearing of the ships to each other or to the land stations —whilst at night interesting and apparently curious results are obtained. Ships over 1,000 miles away, off the south of Spain or round the coast of Italy, can almost always communicate during the hours of darkness with the post-office stations situated on the coasts of England and Ireland, whilst the same ships, when at a similar distance on the Atlantic to the westward of these islands and on the usual track between England and America, can hardly ever communi-

[1] Philosophical Magazine, ser. 6, vol. 4, p. 253.

cate with these shore stations unless by means of specially powerful instruments.

It is also to be noticed that in order to reach ships in the Mediterranean the electric waves have to pass over a large portion of Europe and, in many cases, over the Alps. Such long stretches of land, especially when including very high mountains, constitute, as is well known, an insurmountable barrier to the propagation of short waves during the daytime. Although no such obstacles lie between the English and Irish stations and ships in the North Atlantic en route for North America, a night transmission of 1,000 miles is there of exceptionally rare occurrence. The same effects generally are noticeable when ships are communicating with stations situated on the Atlantic coast of America.

Although high power stations are now used for communicating across the Atlantic Ocean, and messages can be sent by day as well as by night, there still exist periods of fairly regular daily occurrence during which the strength of the received signals is at a minimum.

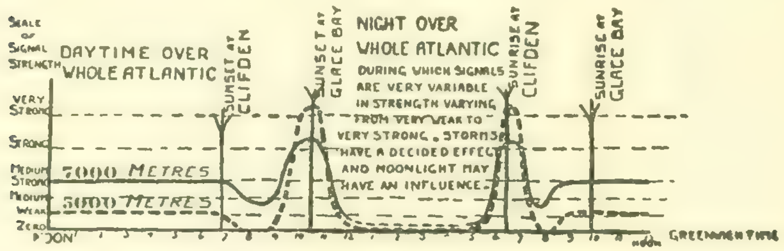


FIG. 8.

Thus in the morning and the evening, when, in consequence of the difference in longitude, daylight or darkness extends only part of the way across the ocean, the received signals are at their weakest. It would almost appear as if electric waves, in passing from dark space to illuminated space and vice versa, were reflected and refracted in such a manner as to be diverted from the normal path.

Later results, however, seem to indicate that it is unlikely that this difficulty would be experienced in telegraphing over equal distances north and south on about the same meridian, as, in this case, the passage from daylight to darkness would occur more rapidly over the whole distance between the two stations.

I have here some diagrams which have been carefully prepared by Mr. H. J. Round. These show the average daily variation of the signals received at Clifden from Glace Bay.

The curves traced on the diagram (fig. 8) show the usual variation in the strength of these transatlantic signals on two wave lengths —one of 7,000 meters and the other of 5,000 meters.

The strength of the received waves remains as a rule steady during daytime.

Shortly after sunset at Clifden they become gradually weaker, and about two hours later they are at their weakest. They then begin to strengthen again, and reach a very high maximum at about the time of sunset at Glace Bay.

They then gradually return to about normal strength, but through the night they are very variable. Shortly before sunrise at Clifden the signals commence to strengthen steadily, and reach another high maximum shortly after sunrise at Clifden. The received energy then steadily decreases again until it reaches a very marked minimum, a short time before sunrise at Glace Bay. After that the signals gradually come back to normal day strength.

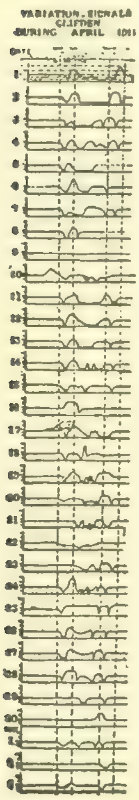


Fig. 9.

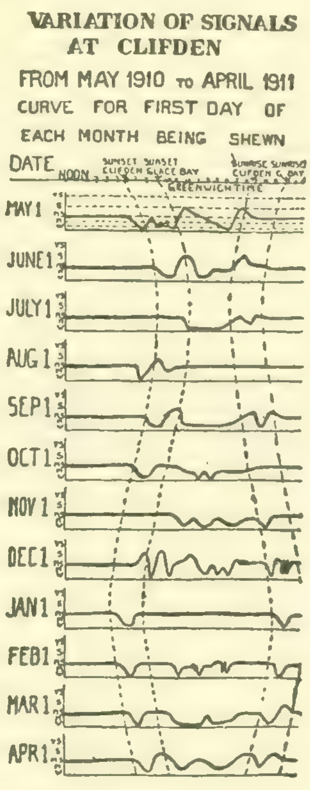


Fig. 10.

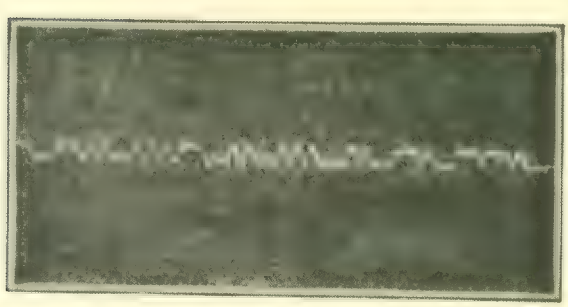
It can be noticed that, although the shorter wave gives on the average weaker signals, its maximum and minimum variations of strength very sensibly exceed that of the longer waves.

Figure 9 shows the variations at Clifden during periods of 24 hours, commencing at 12 noon throughout the month of April, 1911, the vertical dotted lines representing sunset and sunrise at Glace Bay and Clifden.

Figure 10 shows the curve for the first day of each month for one year, from May, 1910, to April, 1911.

I carried out a series of tests over longer distances than had ever been previously attempted, in September and October of last year, between the stations of Clifden and Glace Bay, and a receiving station placed on the Italian Steamship *Principessa Mafalda,* in the course of a voyage from Italy to Argentina (pl. 1, fig. 1).

1. LONG DISTANCE WIRELESS TESTS IN 1910.



2. RECORD OF WIRELESS SIGNALS.

During these tests the receiving wire was supported by means of a kite, as was done in my early transatlantic tests of 1901, the height of the kite varying from about 1,000 to 3,000 feet. Signals and messages were obtained without difficulty, by day as well as by night, up to a distance of 4,000 statute miles from Clifden.

Beyond that distance reception could only be carried out during nighttime. At Buenos Aires, over 6,000 miles from Clifden, the night signals from both Clifden and Glace Bay were generally good, but their strength suffered some variations.

It is rather remarkable that the radiations from Clifden should have been detected at Buenos Aires so clearly at nighttime and not at all during the day, whilst in Canada the signals coming from Clifden (2,400 miles distant) are no stronger during the night than they are by day.

Further tests have been carried out recently for the Italian Government between a station situated at Massaua in East Africa and Coltano in Italy. Considerable interest attached to these experiments, in view of the fact that the line connecting the two stations passes over exceedingly dry country and across vast stretches of desert, including parts of Abyssinia, the Soudan, and the Libyan Desert. The distance between the two stations is about 2,600 miles.

The wave length of the sending station in Africa was too small to allow of transmission being effected during daytime, but the results obtained during the hours of darkness were exceedingly good, the received signals being quite steady and readable.

The improvements introduced at Clifden and Glace Bay have had the result of greatly minimizing the interference to which wireless transmission over long distances was particularly exposed in the early days.

The signals arriving at Clifden from Canada are as a rule easily read through any ordinary electrical atmospheric disturbance. This strengthening of the received signals has moreover made possible the use of recording instruments, which will not only give a fixed record of the received messages, but are also capable of being operated at a much higher rate of speed than could ever be obtained by means of an operator reading by sound or sight. The record of the signals is obtained by means of photography in the following manner: A sensitive Einthoven string galvanometer is connected to the magnetic detector or valve receiver, and the deflections of its filament caused by the incoming signals are projected and photographically fixed on a sensitive strip, which is moved along at a suitable speed (pl. 1, fig. 2). On some of these records, which I am able to show, it is interesting to note the characteristic marks and signs produced amongst the signals by natural electric waves or other electrical disturbances of

the atmosphere, which, on account of their doubtful origin, have been called "X's."

Although the mathematical theory of electric wave propagation through space was worked out by Clerk Maxwell more than 50 years ago, and notwithstanding all the experimental evidence obtained in laboratories concerning the nature of these waves, yet so far we understand but incompletely the true fundamental principles concerning the manner of propagation of the waves on which wireless telegraph transmission is based. For example, in the early days of wireless telegraphy it was generally believed that the curvature of the earth would constitute an insurmountable obstacle to the transmission of electric waves between widely separated points. For a considerable time not sufficient account was taken of the probable effect of the earth connection, especially in regard to the transmission of oscillations over long distances.

Physicists seemed to consider for a long time that wireless telegraphy was solely dependent on the effects of free Hertzian radiation through space, and it was years before the probable effect of the conductivity of the earth was considered and discussed.

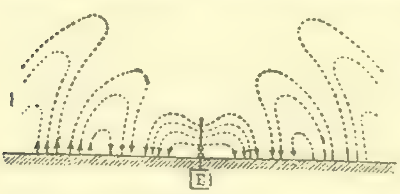


FIG. 11.

Lord Rayleigh, in referring to transatlantic radiotelegraphy, stated in a paper read before the Royal Society in May, 1903, that the results which I had obtained in signaling across the Atlantic suggested "a more decided bending or diffraction of the waves round the protuberant earth than had been expected," and further said that it imparted a great interest to the theoretical problem.[1] Prof. Fleming, in his book on electric wave telegraphy, gives diagrams showing what may be taken to be a diagrammatic representation of the detachment of semiloops of electric strain from a simple vertical wire (fig. 11).

As will be seen, these waves do not propagate in the same manner as does free radiation from a classical Hertzian oscillator, but instead glide along the surface of the earth.

Prof. Zenneck[2] has carefully examined the effect of earthed receiving and transmitting aerials, and has endeavored to show mathematically that when the lines of electrical force, constituting a wave front, pass along a surface of low specific inductive capacity—such as the earth—they become inclined forward, their lower ends being retarded by the resistance of the conductor, to which they are

[1] Proc. Roy. Soc., vol. 72, p. 40.

[2] "Annalen der Physik," vol. 23, p. 846, "Physikalische Zeitschrift," 1908, pp. 50, 553.

attached. It therefore would seem that wireless telegraphy as at present practiced is, to some extent at least, dependent on the conductivity of the earth, and that the difference in operation across long distances of sea compared to over land is sufficiently explained by the fact that sea water is a much better conductor than is land.

The importance or utility of the earth connection has been sometimes questioned, but in my opinion no practical system of wireless telegraphy exists where the instruments are not in some manner connected to earth. By connection to earth I do not necessarily mean an ordinary metallic connection as used for wire telegraphs. The earth wire may have a condenser in series with it, or it may be connected to what is really equivalent, a capacity area placed close to the surface of the ground. It is now perfectly well known that a condenser, if large enough, does not prevent the passage of high-frequency oscillations, and therefore in this case, when a so-called balancing capacity is used, the antenna is for all practical purposes connected to earth.

I am also of opinion that there is absolutely no foundation in the statement which has recently been repeated to the effect that an earth connection is detrimental to good tuning, provided of course that the earth is good.

Certainly, in consequence of its resistance, what electricians call a bad earth will damp out the oscillations, and in that way make tuning difficult; but no such effect is noticed when employing an efficient earth connection.

In conclusion, I believe that I am not any too bold when I say that wireless telegraphy is tending to revolutionize our means of communication from place to place on the earth's surface. For example, commercial messages containing a total of 812,200 words were sent and received between Clifden and Glace Bay from May 1, 1910, to the end of April, 1911; wireless telegraphy has already furnished means of communication between ships and the shore where communication was before practically impossible. The fact that a system of imperial wireless telegraphy is to be discussed by the imperial conference, now holding its meetings in London, shows the supremely important position which radiotelegraphy over long distances has assumed in the short space of one decade. Its importance from a commercial, naval, and military point of view has increased very greatly during the last few years as a consequence of the innumerable stations which have been erected, or are now in course of construction, on various coasts, in inland regions, and on board ships in all parts of the world. Notwithstanding this multiplicity of stations and their almost constant operation, I can say from practical experience that mutual interference between properly equipped and efficiently tuned instru-

ments has so far been almost entirely absent. Some interference does without doubt take place between ships, in consequence of the fact that the two wave lengths adopted in accordance with the rules laid down by the international convention, are not sufficient for the proper handling of the very large amount of messages transmitted from the ever increasing number of ships fitted with wireless telegraphy. A considerable advantage would be obtained by the utilization of a third and longer wave to be employed exclusively for communication over long distances.

In regard to the high-power transatlantic stations, the facility with which interference has been prevented has to some extent exceeded my expectations. At the receiving station situated at a distance of only 8 miles from the powerful sender at Clifden, during a recent demonstration arranged for the Admiralty, messages could be received from Glace Bay without any interference from Clifden when this latter station was transmitting at full power on a wave length differing only 25 per cent from the wave radiated from Glace Bay, the ratio between the maximum recorded range of Clifden and 8 miles being in the proportion of 750 to 1.

Arrangements are being made to permanently send and receive simultaneously at these stations, which, when completed, will constitute in effect the duplexing of radiotelegraphic communication between Ireland and Canada.

The result which I have last referred to also goes to show that it would be practicable to operate at one time, on slightly different wave lengths, a great number of long-distance stations situated in England and Ireland without danger of mutual interference.

The extended use of wireless telegraphy is principally dependent on the ease with which a number of stations can be efficiently worked in the vicinity of each other.

Considering that the wave lengths at present in use range from 200 to 23,000 feet, and moreover that wave group tuning and directive systems are now available, it is not difficult to foresee that this comparatively new method of communication is destined to fill a position of the greatest importance in facilitating communication throughout the world.

Apart from long-distance work, the practical value of wireless telegraphy may perhaps be divided into two parts, (1) when used for transmission over sea and (2) when used over land.

Many countries, including Italy, Canada, and Spain, have already supplemented their ordinary telegraph systems by wireless-telegraphy installations, but some time must pass before this method of communication will be very largely used for inland purposes in Europe generally, owing to the efficient network of land lines already existing which render further means of communication unnecessary; and

therefore it is probable that, at any rate for the present, the main use of radiotelegraphy will be confined to extra-European countries, in some of which climatic conditions and other causes absolutely prohibit the efficient maintenance of land-line telegraphy. A proof of this has been afforded by the success which has attended the working of the stations recently erected in Brazil on the upper Amazon.

By the majority of people the most marvelous side of wireless telegraphy is perhaps considered to be its use at sea. Up to the time of its introduction, ships at any appreciable distance from land had no means of getting in touch with the shore throughout the whole duration of their voyage. But those who now make long sea journeys are no longer cut off from the rest of the world; business men can continue to correspond at reasonable rates with their offices in America or Europe; ordinary social messages can be exchanged between passengers and their friends on shore; a daily newspaper is published on board most of the principal liners, giving the chief news of the day. Wireless telegraphy has on more than one occasion proved an invaluable aid to the course of justice—a well-known instance of which is the arrest, which took place recently through its agency, of a notorious criminal when about to land in Canada.

The chief benefit, however, of radiotelegraphy lies in the facility which it affords to ships in distress of communicating their plight to neighboring vessels or coast stations; that it is now considered indispensable for this reason is shown by the fact that several governments have passed a law making a wireless-telegraph installation a compulsory part of the equipment of all passenger boats entering their ports.

RECENT DEVELOPMENTS IN THE WORK OF THE FEDERAL TELEGRAPH COMPANY

Lee de Forest

RECENT DEVELOPMENTS IN THE WORK OF THE FEDERAL TELEGRAPH COMPANY.*

By LEE DE FOREST, Ph. D.
Engineer of the Federal Telegraph Co.

The Federal Telegraph Company is unique in several respects. Among these, it enjoys the distinction of employing no press agents. Consequently in the East almost nothing is known of what is being done in the West. This is, of course, regrettable from a technical standpoint.

The present chain of stations of the company comprises those at Seattle, Portland, Medford, Central Point, Sacramento, Phoenix, San Diego, El Paso, Fort Worth, Chicago and others. Tho messages have been sent from San Francisco to Chicago, the service is not of the same character as that maintained on the Pacific Coast, which latter is strictly commercial. The largest of all these stations are those at San Francisco and Honolulu. Each of these has a power of 40 kilowatts, which is to be increased to 60 kilowatts.

We operate under the Poulsen patents. But the apparatus imported from Denmark in 1910, showed many commercial defects and lack of reliability. The cooling appliances were inadequate, and the insulation faulty.

The system, as now in use, is the simplest imaginable, particularly at the transmitter end. Referring to Figure 1, E is a direct current generator of 500 to 1,000 volts or even more, D are choke coils intended to prevent the alternating current from the arc flowing back to the generator and also intended to keep the generator direct current constant, A is the arc itself, B a tuning or loading inductance, and T the antenna. The arc itself plays between a copper positive electrode and a carbon negative electrode. It is always water cooled. It is in an intense magnetic field, and the atmosphere surrounding it is usually illuminating gas. Where this cannot be obtained, denatured alcohol is used instead. If desired, ether can be added to the denatured alcohol.

In this system the transmitting key is used, not as in most

* Lecture delivered before The Institute of Radio Engineers, November 6th, 1912, at Fayerweather Hall, Columbia University.

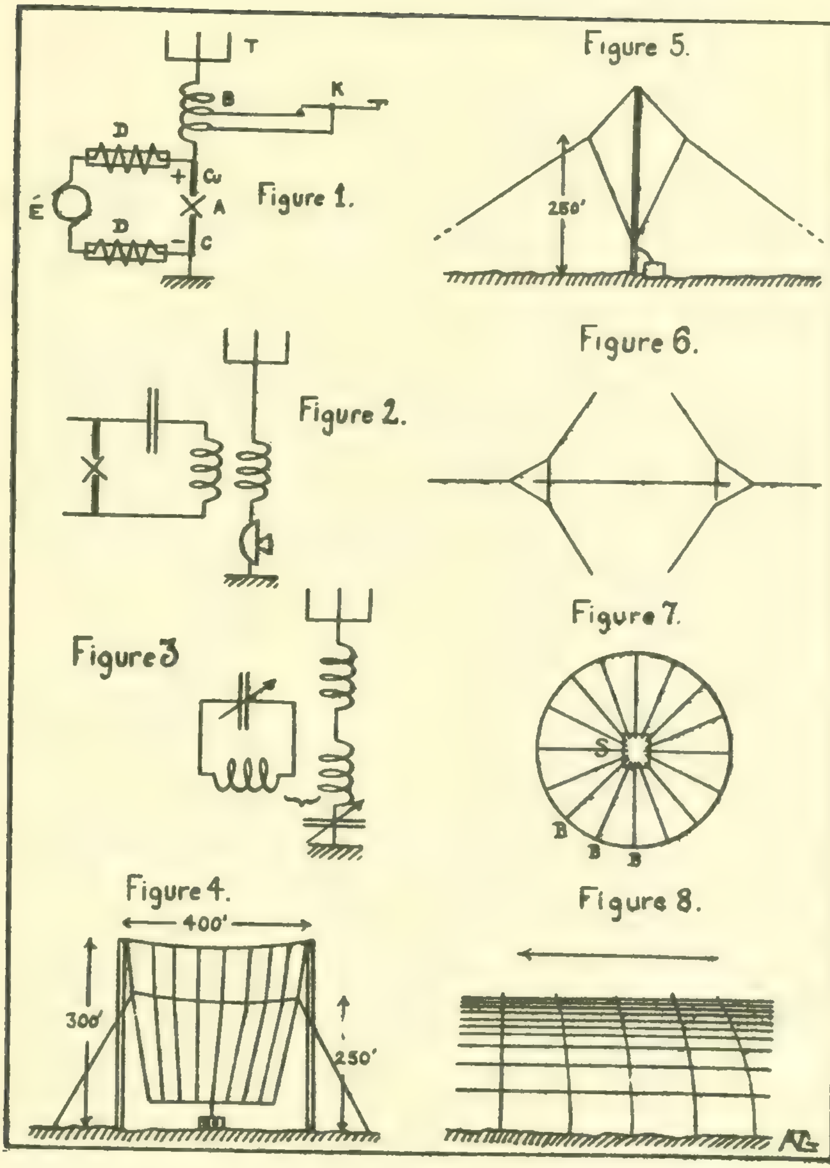


Figure 1.

Figure 2.

Figure 3

Figure 4.

Figure 5.

Figure 6.

Figure 7.

Figure 8.

stations to change the amount of energy emitted, but only to alter slightly the wave length. This is accomplished by connecting the key K as shown across one or two turns of the inductance B. When the key is pressed, the wave emitted is lengthened by say five per cent. So that all the time transmission is going on the antenna is radiating. This makes matters interesting but unsatisfactory for the amateur interloper who naturally fails to separate the two waves and interpret the messages. The wave not used for receiving, which is usually the shorter one, is termed the "compensation" wave, and the tuning at the receiving station must be sufficiently sharp to ensure that the compensation wave shall not be heard. It has been found that smaller amateur stations even in the neighborhood of the twelve kilowatt station cannot tune up to the longer wave, and this fact ensures their reception of what may be called reversed, and of course unreadable messages. We feel responsible for a state of thorough disgust on the part of said amateurs.

Furthermore, when in the immediate neighborhood of a powerful station of the Poulsen type, the received signals from other stations are considerably fainter when transmission is going on from the arc station. This may be due to either a surplus of energy passing thru the detector and rendering it insensitive; or to rendering partially opaque the transmitting medium by the undamped radiations.* I must admit that I cannot see just how this latter alternative can be the case tho it is difficult otherwise to explain the fact that even with the Audion detector the smothering effect is shown. For the effect mentioned, the arc may be as much as five miles distant, from the detector affected, and yet the signals from spark stations will drop to a marked degree.

It is of interest that the arc length or changes in it have practically no effect on the radiation, at least for telegraphy. For telephony, the constant conditions required are naturally more severe. For telephony, the double circuit arrangement shown in Figure 2 is used. The conditions being more critical in this case, the operator is required to watch the arc and keep it steady by occasional manipulation. The skill required is not great.

The receiving circuit ordinarily employed is shown in Figure 3. The coupling between the antenna circuit and the closed circuit is usually very loose. Thus with pancake shaped coupling coils such values of the angle between the coils as 88° are usual.

* See Editorial Notes at the end of this Lecture.

This is exceptionally loose coupling and ensures sharp tuning of a quality unattainable in spark systems. The tuning is remarkably sharp and we have done much work in the direction of eliminating damping in the receiving circuits. In particular we have found it necessary to avoid leaky condensers. And because of the undamped nature of the radiation we can get all the advantages of loose coupling.

The detector used is the ticker. The old-style ticker is an intermittent contact operated by an electric buzzer. The contacts themselves are between two gold wires, one of them fixed and the other attached thru an insulating piece to a diaphragm which is maintained in continual vibration by the buzzer armature. The contact wires are connected to the terminals of the tuning condenser in the closed tuning circuit and also to a considerably larger fixed condenser (value about 0.02 mfd.), which latter condenser is also connected to the low resistance receiving telephones. The action of the ticker is to permit alternating currents of large amplitude to build up in the secondary tuning circuit, and at more or less regular intervals to discharge the variable condenser thru the telephones producing at each discharge a click. The telephones are the ordinary 75 ohm double head band type. The note produced is not a pure musical one because the ticker cannot be arranged so as to interrupt the alternating current which charges the condenser at the same point of the cycle at successive interruptions. In consequence some clicks are louder than others and the note is not clear. It may be characterized as a hissing sound not altogether agreeable to the ear. If a rectifier is placed in the ticker circuit the note becomes much purer. But the signals are weakened.

The difference between the two waves emitted from the transmitter is small. Thus when the sending key is up the wave may be 3000 meters and it may be 3150 meters when the key is depressed.

An efficiency of twenty per cent. is considered good for the Poulsen transmitter. Tho this is only about one-third what is obtained by the use of the quenched spark, yet it is found that in practice we can work far greater distances than with the latter. This may be because the ticker telephone combination is by far the most sensitive and efficient detector in existence.

As examples of what is done as regular service, we work from Los Angeles to San Francisco, a distance of 350 miles with 12 kilowatts direct current. San Diego, with 5 kilowatts D. C.

is in communication with San Francisco at night. In the winter, the conditions are naturally much better. With 12 kilowatts D. C. we even work from San Francisco to El Paso in the daytime, a distance of 900 miles; not sufficiently continuously for commercial service but still very frequently; it being practically a daily performance.

The power utilized is limited by two considerations. One of these is the capacity of the antenna and the other is the voltage at the arc. We have worked up to 1200 volts but higher voltages than this are not excluded. As to the antennae, we have adopted as standard the double harp, twin-mast system. Its construction is clearly shown in Figures 4 and 5 which are those of a typical antenna of 0.005 mfd. capacity. The new antenna for the large South San Francisco station is supported by twin towers 440 feet high, 600 feet apart. The antenna capacity is here 0.012 mfd. Because of the low voltages employed, insulation difficulties are minimized. The type of tower now used is triangular in cross section and does not taper. For it special timbers have to be sawed. The plan of the guying system is shown in Figure 6. It will be seen that the construction lends itself to great rigidity. As the results of our tests with the 12 Kilowatt stations we have reached the conclusion that this type of masts and antenna is the best for our system. In some of our stations, we employ the flat top aerial of less height for receiving. But we regard the flat top aerial as inferior to the harp type. The harp type also has the mechanical advantage that by its use the danger of twisting of the spreaders disappears.

The ground employed is the radial type with connection to earth at outer points. It is shown in Figure 7, where S is the station house. The ground wires, which are buried two or three feet below the surface radiate in all directions, and are heavily bonded together at their outer extremeties, B.

At the South San Francisco station, the antenna current is about 40 amperes when 35 kilowatts is drawn from the direct current generator at 600 volts. The Honolulu Station is exactly like the South San Francisco one. The system as now improved is simple in operation and installation. As evidence of this, Mr. Elwell, Chief Engineer of the company, went to Honolulu on two days notice, and within sixty days the Honolulu station was in operation. And yet in this case there were considerable difficulties to be overcome. All the apparatus and supplies had to be shipped from San Francisco, and the Chinese workmen, who

were the only ones available, would not work at heights above one hundred feet. The distance covered by this station is 2300 miles. Since August, not less than 1500 to 2500 words of press have been transmitted daily. There are in addition a considerable number of paid messages. The rate is 25 cents a word against 35 cents of the cable companies. At the present time, we can operate up to 8 in the morning. When the new 60 kilowatt sets are installed, we expect to operate thruout the day.*

Between Los Angeles and San Francisco two to three hundred messages are sent every day, and this is strictly paid business, of a kind where accurate service is required. Of course, a certain type of customers is specifically catered to. Thus the California Fruit Growers Association do much business between Los Angeles and San Francisco. They demand a thirty minute service, that is, between sending the message and receiving the answer, and we have kept up that service for over a year now. This is a very strict test because these messages are all in an unpronounceable code. The Publishers' Press Association has also used our service from five to nine in the evening for a period of ten months or more.

There is another chain of stations at the following points: Chicago, Kansas City, El Paso, and Fort Worth. But these stations were equipped with too little power. The static in Texas is terrific and prevents service except in the daytime. At Chicago there are two 80 foot towers, 250 feet apart, placed at the top of a high building. They each carry 40 foot spreaders. The limit of power capacity here is 7.5 kilowatts, the limit in this case, being determined by the dimensions of the antenna. If greater power is desired, it will be necessary to use higher voltage.

An extremely interesting phenomenon has been observed in this work with undamped radiations of slightly different wave lengths. It is that at certain times daily, practically thruout the year, and under certain meteorological conditions, very surprising variations in the strength of the received signals occur when definite wave lengths are used, and only when these wave lengths are used. For example, the Los Angeles station works with a wave of 3260 meters and a compensation wave of 3100 meters, and the shorter wave is radiated continuously with the exception of the time during which the dashes or dots are being sent.

Now it will suddenly happen that the longer wave will become

* Since this paper was prepared 24-hour service, both ways, has been instituted and is daily successfully maintained.

very weak or even be entirely lost at the San Francisco station, distant 350 miles north, whereas it will be received with normal strength at the Phoenix, Arizona station, distant 300 miles to the east. Nevertheless the shorter compensation wave, which differs in wave length by only about 5 per cent., will be received in San Francisco with full strength, or even with greater intensity at times.

This phenomenon of the extinction of the waves occurs frequently, particularly at our stations near the Pacific Ocean; for weeks it was observed every evening and at other times was entirely absent. In consequence the operators have arranged to send on either of the two waves used.

The duration of this fading effect is often several hours after nightfall; then it suddenly vanishes and thereafter both waves have their normal intensity. This alteration of intensity is sometimes for one wave, and sometimes for the other, and rarely for both; and in the last mentioned case the operator can find a third wave on which he can receive clearly. Usually, however, one of the wave remains of normal intensity; in other words, waves which differ in length by several hundred meters do not vanish simultaneously.

This selective absorption does not seem to be limited to specific localities, appears mostly at sunset, lasts far into the night, but is seldom observed near noon.

At first I thought that the effect could be explained by altered conditions at the transmitter or receiving station, as, for example, thru alteration of antenna capacity because of the presence of fog, etc. But the persistency with which it occurred, and the fact that no amount of tuning at the receiving station remedied matters altho simultaneously other stations were receiving this wave perfectly, prevents the acceptance of an explanation on the grounds of atmospheric absorption, that is, such an explanation as is employed to clear up the daylight absorption at long ranges.

Clearly it is impossible that a wave of 3260 meters previously of satisfactory intensity can be absorbed completely at a distance of 350 miles while at the same time a wave of 3100 meters remains of full strength. And there is not much to be said in favor of the assumption that alterations of the refractive power of low-hanging cloud banks or of layers of clouds produce a bending of the wave trains which causes them to pass over the receiving station, while at the same time waves of only 5 per cent. differ-

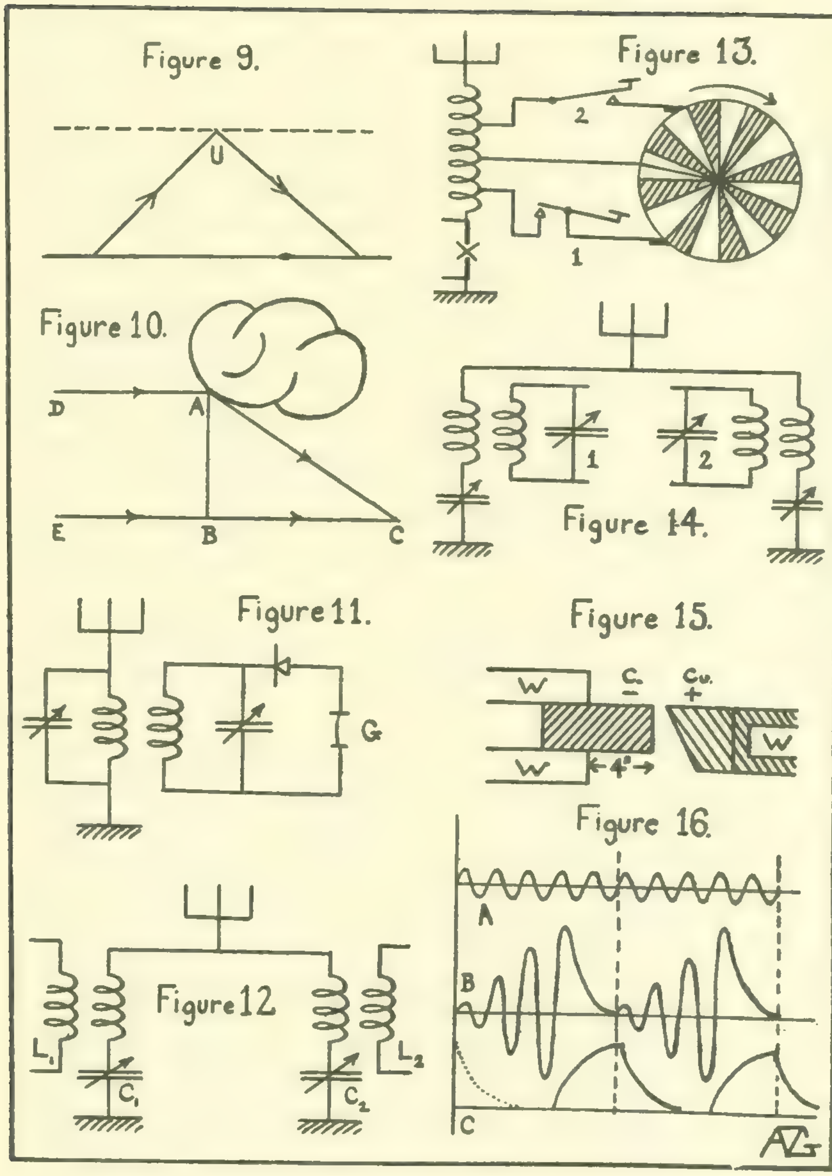


Figure 9.
U
Figure 10.
D
A
E
B
C
Figure 11.
G
Figure 12
L_1
C_1
C_2
L_2
Figure 13.
2
1
Figure 14.
1
2
Figure 15.
W
C.
Cu.
W
4°
W
Figure 16.
A
B
C

ence in length are received as well, or even more strongly (as is frequently observed).

It is however possible, that under certain atmospheric conditions, which may be caused by clouds or masses of fog (which are found with great regularity at certain seasons on the Pacific coast), or by by partially ionized masses of air at greater heights. the energy of the upper part of the wave may be deflected or bent downward. Dr. Eccles at the Dundee meeting of the British Association pointed out that a bending of the wave as it travelled might be produced if the upper layers of air were even partly conducting. The appearance of the bending wave front as it travels from left to right is shown in Figure 8. Under such conditions there are acting at the receiving stations two trains of waves which have travelled over paths of unequal lengths or which have travelled with unequal velocities. Consequently there will be a phase displacement between them and interference at certain localities. These are the nodes at which total or partial extinction of the oscillations occurs.

The possibility of such an interference has already been mentioned by several authors in their speculations concerning the propagation of electric waves over the surface of the earth. For example, Professor Pierce, of Harvard University, states in his book: "Principles of Wireless Telegraphy," "The upper layers of the atmosphere which have been rendered conducting thru the action of sunlight, may act to a certain extent as reflectors of electric waves and thus limit their propagation over the surface of the earth; the transmission would then be superior in the day time, with the exception of the case where a possible interference occurred between the direct and reflected waves. This interference, if it exists, would strengthen waves of certain length and might annihilate waves of different length, so that this interference could be made of assistance by altering the wave length by an amount corresponding to half the period. No such effects however have been observed."

Dr. Pierce's conclusions regarding the superiority of daylight transmission are, as you know, contradicted by the experimental results. The ionization of the air at lower levels is able to counteract the influence of the reflection at the upper layers. On the other hand I believe that there is now ample evidence to concede the existence of such reflection as darkness approaches. In Figure 9, the conducting layer of air at U is shown and the path of the wave with its reflection at U is also shown.

How shall we account for the fact that the reflection effect was not observed till recently? In spark telegraphy two waves of nearly equal length were rarely used (with the exception of the case of those due to coupling of the open and closed oscillating circuits). Alterations in the wave length used in transmission are seldom attempted or else are of considerably greater magnitude than those used in our work with continuous oscillations, which latter therefore bring the desired effect into greater prominence. It would be interesting to observe whether similar observations have been recorded with sustained radiation in other climates, or whether these effects are limited to the particular atmospheric conditions and localities in which we have observed then.

Because of the great commercial demands on the stations up to the present time I have not been able to undertake a careful series of observations altering the transmitting wave by successive small steps in order to ascertain between what intervals of wave length these effects of interference or disappearance pass thru maxima and minima. Before an exact statement can be made theory and practice must work together for some time.

In Figure 10 is illustrated one set of conditions which would lead to the reflection and interference effects observed. Suppose we are working with two waves, λ_2, of length 3000 meters and λ_1 of 3150 meters. At A assume a reflecting surface (cloud bank or mass of ionized atmosphere). The distance BC is taken as $20\lambda_1$ which equals $21\lambda_2$. The distance AC is taken as $28.5\lambda_1$ which also equals $29.9\lambda_2$. So that the difference of the paths for the two waves λ_1 and λ_2 is $28.5 - 20 = 8.5\lambda_1$ for the first wave, and $29.9 - 21 = 9.0\lambda_2$ for the second wave. The height AB is found to be 37.5 miles in this case. Its height is found to depend on its distance from the sending and receiving station provided the differences of paths of the two waves are assumed known. It will be seen that in this case the longer wave will arrive at C by two paths which bring the two portions of the wave to C in directly opposite phases. In consequence the longer wave will be partially or totally annulled at C. On the other hand, the shorter wave travels to C by two paths which bring the two portions of the wave to C in phase. They therefore reinforce each other and may appear with increased intensity. Other values for AB, BC, and AC are 27.7 miles, $10\lambda_1$ or $10.5\lambda_2$, and $18\lambda_1$ and $18.9\lambda_2$ respectively. Yet another set of values is 17 miles, $3\lambda_1$ or $3.15\lambda_2$, and $10\lambda_1$ and $10.5\lambda_2$ respectively.

Figure 17

Figure 18

Figure 19

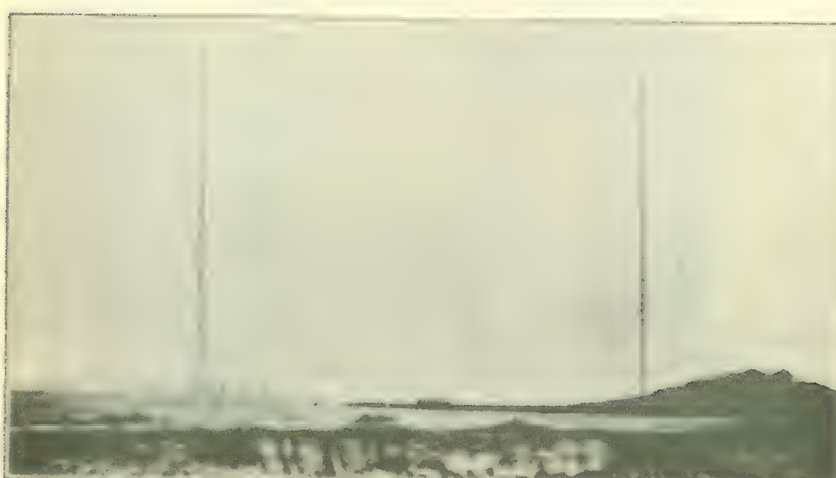


Figure 20

Figure 21

Figure 22

Figure 23

If the reflecting layer is half way between the stations, its height is 62 miles under the conditions here assumed. Five minutes is sometimes the interval during which the effect persists. For its disappearance the ionized layer need rise only one-half of one wave length. Almost never have both the waves faded at the same time. This shows that the reflecting stratum is at a great height. I believe that prolonged and tabulated observations will add considerably to our theoretical knowledge of this subject.

It is possible that the so-called "freak work" in wireless is due to this interference effect. It is impossible to say because we have had no simple way of changing the wave length suddenly in the quenched spark sets. But I believe that the extreme long distance work done by small sets must frequently be explained thus. Then too, it would account for the fact that the Marconi Transatlantic stations can operate sometimes with a few kilowatts and sometimes require 125 to 600 kilowatts.

And finally, to return to our commercial work, we now use a wave length of 5000 meters at our South San Francisco station. Thus we avoid interference with neighboring spark stations, altho properly tuned quenched sparks sets with a wave length differing 8 per cent. from our own do not interfere with us. It has been our aim to conduct our business with maximum certainty and minimum of interference, and we have succeeded so well in the first aim that we believe that any failure in the second is rather the fault of the other systems.

EDITORIAL NOTES.

Thru the kindness of the Federal Telegraph Company and Mr. Elwell a number of photographs illustrating the work of the company are here reproduced. Figure 17 is the antenna at San Diego. It is of the earlier double pole and spreader type. Figure 18 is the station at Portland, Oregon. The towers are square in cross section. A newer type of tower construction, namely the triangular cross-section type, is shown in Figure 19, the Central Point, Oregon, station. The Transpacific South San Francisco station is shown in Figure 20. In Figure 21 is shown the interior of the Central Point station. To the left is the 500 volt direct current control board with generator field rheostat, measuring

instruments, and breaker. Next to it can be seen the arc converter with its powerful field magnets, arrangements for artificial cooling, and front button which, when pressed, makes contact and starts the arc. To the left of the operator's table is seen the receiving set with variable inductances and capacities controlled from the front knobs, various switches for altering wave length range, etc., and the telephone jacks. Standing on the top of the receiving set is a specially wound coil which is employed when extra long waves are to be received. Next to the receiving set is the operator's key, and then the board where the wave length of the radio-frequency currents is controlled. The antenna hot wire meter is visible at the top of this board, and below it a rotary switch which enables the operator to rapidly change the wave length, which procedure, from the foregoing article, will be seen to be strictly necessary at times. To the extreme right of the operator's table is the motor-driven ticker for receiving. It is supplied in duplicate. At the top of the room is seen the antenna helix with the various taps leading to it. Near its bottom and to its right is seen the lightning switch.

The details of the transmitting apparatus are shown in Figures 22 and 23. Figure 22 shows the new Poulsen generator with special anode. There is a quick detachable bottom plug for cleaning the arc chamber when necessary. The massive field coils are shown. They are wound with heavy square cross section copper wire. Figure 23 shows the arc and its control board. Under the switch-board panel are shown the water valve lever which controls the flow of water thru the arc chamber jacket, and the receiving contact device. Both of these are operated by the large triple pole switch. This switch controls the flow of water, the flow of gas, the motor for rotating the carbon electrode of the arc, the power current, the radio-frequency circuit, the receiver circuit, and the motor-driven tickers.

The hypothesis suggested tentatively by Dr. de Forest relative to the opacity of the ether for certain wave lengths has, up to the present time, met with no substantiation. We are forced to regard it as highly improbable. The view that the interference effects are the results of the joint action of the direct and reflected waves, as also suggested by Dr. de Forest, is very probably correct, and should lead to valuable and extended researches on the most favorable locations of stations and wave lengths to be employed.

In order to render the action of the ticker somewhat more clear Figure 16 is inserted. It is intended to show the currents in the various circuits. Curve A gives the antenna current. Curve

B gives the current in the secondary tuned circuit. Curve C gives the condenser discharge current thru the telephone receiver. It will be noted how the resonance effects which are obtainable with sustained alternating current in the antenna are utilized fully. This ingenious receiving device is due to Prof. P. O. Pederson of Copenhagen.

The circuit arrangements for which these diagrams apply are somewhat different from those now employed, but embody the same principle.

Dr. de Forest has formally notified the Editor of the results of the tests at the Arlington station. The 30 Kilowatt arc was first tested on December 8th. Two way communication with South San Francisco, and also with Honolulu, was almost immediately established, altho at the time Honolulu was still in daylight! Owing to the greater height (600 feet) of the Arlington antenna, its signals are received with greater intensity than those of the latter station at Arlington. The energy used at Arlington was from 35 to 40 K. W.

ALFRED N. GOLDSMITH, PH.D.

DISCUSSION.

E. J. SIMON: I understand that using 35 kilowatts at the San Francisco station the antenna current is 40 amperes. What is the radiation resistance?

DR. DE FOREST: We have not measured it because it cannot be accomplished in the usual way, namely by the insertion of resistance in the antenna. The arc is directly in that circuit, and any change alters the conditions markedly.

DR. GOLDSMITH: It should be possible to accomplish the desired result thru the following means. Measure the arc voltage which is applied to the antenna (R. M. S. value of the alternating E. M. F.) by means of an electrostatic voltmeter. Then measure the effective inductance and capacity of the antenna at the desired wave length or frequency ω separately. Then if R is the radiation and ohmic resistance of the antenna, L and C its effective inductance and capacity, E and I the R. M. S. values of the voltage and amperage of the antenna, we have

$$R = \sqrt{\frac{E^2}{I^2} - \left(L\omega - \frac{1}{C\omega}\right)^2}.$$

E. J. Simon: We may determine the damping by measuring the decrement by the Bjerknes method.

Dr. Goldsmith: Before employing either of the above methods it would be well to calculate what effect the non-sinusoidal character of the arc current would have on the results.

E. J. Simon: An artificial antenna or substitution method might be employed.

R. A. Weagant: In this case air condensers should be used in the artificial antenna.

E. J. Simon: Does the ground extend beyond the horizontal projection of the antenna?

Dr. de Forest: Yes; the extreme spread of the antenna is 400 feet, but the radius of the ground is 350 feet.

E. J. Simon: The signals weaken in the morning. Is there any definite lag of the change of intensity of the signal as compared with the time of sunrise?

Dr. de Forest: We have as yet made no such quantitative measurements.

R. A. Weagant: How loose is the coupling used in receiving?

Dr. de Forest: Usually 10 to 15%. In cases of bad static it may be 5%.

E. J. Simon: Do you use the longer wave because of its greater energy?

Dr. de Forest: Yes, and to prevent interference, but the energy difference is small.

E. J. Simon: What is the fundamental of the South San Francisco aerial?

Dr. de Forest: About 2800 meters.

Dr. Goldsmith: Will you describe the automatic sender, the optical printing receiver, and the diplex transmission and reception methods?

Dr. de Forest: For high speed transmission we employ an automatic sender. For receiving at high speeds we use the Einthoven thread galvanometer, which consists of a fine thread of gold wire in an intense field of an electromagnet. It is placed in series with a rectifying detector and on receipt of incoming signals is slightly deflected. By suitable optical systems, a greatly enlarged shadow of the brilliantly illuminated wire is thrown on a moving strip of photographically sensitive paper, which is then

rapidly developed and fixed. From the wavy line on the strip of paper the message can be read. We have spent over $12,000 in investigating this method, and have imported the best instruments we could get in Denmark and Germany. But the entire method is impractical commercially and a flat failure. And it always will be. The Pederson high speed transmitting key is a device which is operated by punched tape such as is used in the Wheatstone sender. It is a somewhat complicated device which acts on the principles that small rotating rods, released by mechanical means, close light contacts and thereby permit heavier rotating contacts, which are always in readiness to operate, to add aerial inductance and thereby increase the wave length. The arrangement of circuits used with the Einthoven galvanometer is shown in Figure 11. The galvanometer is shown at G. The wire in it is 0.00005 of an inch in diameter. Our experience with it has been unsatisfactory. Static is sufficient to throw the spot of light completely off the moving paper strip, and we sometimes had to run the paper thru three times, and even three times three times, before a good record was secured. Even the possibility of sending more than 100 words per minute does not compensate for such disadvantages. A possible method of diplex is shown in Figure 12, where L_1 and L_2 are the primaries from which energy at different wave lengths is transferred to the antenna. Marconi tried something of the sort, but omitted the condensers C_1 and C_2, hence it is very doubtful whether the device operates as then shown. An extremely successful method of diplex operation is shown in Figure 13. It will be noticed that the contacts on the rotating sector wheel are so arranged that contact for key 2 is broken just as contact for key 1 is made. When neither key is depressed a medium wave of length 3200 meters, for example, will be sent. If key 1 is depressed the wave length rises to 3400 meters, and if key 2 is depressed a wave length of 3000 meters is emitted. If both keys are depressed, waves of length 3000 and 3400 are alternately sent out for short intervals of time. The arrangement at the receiving station is shown in Figure 14, where 1 and 2 are the two receiving circuits tuned to 3400 and 3000 meters respectively. This system has worked perfectly between Los Angeles and San Francisco. It is very practical, and arcing at the brushes has been largely overcome. I use 450 interruptions per second.

John L. Hogan, Jr.: Have you any data as to the decrement of your receiving antenna circuit? You speak of extremely sharp resonance.

DR. DE FOREST: Stress of commercial business at the San Francisco station has prevented our making such measurements.

J. L. HOGAN, JR.: What is the comparative sensitiveness of the "Ticker" as compared with the solid rectifiers?

DR. DE FOREST: Qualitatively I should say that the ticker was about three times more sensitive. We get louder signals with the ticker signals from the arc station than we can get when we employ a "chopper" at the transmitting station to break up the outgoing wave train, and a rectifier at the receiving station. To give you an idea of the actual intensity of the signals, at Los Angeles the operators invariably use the typewriter while receiving.

J. L. HOGAN, JR.: Is the ticker ever run at interrupter frequencies as high as 1000 or 1200 per second?

DR. DE FOREST: No, the normal rate is about 200 per second. This gives a hissing note in the telephone receiver, a sound which is very characteristic, and easily read when one becomes accustomed to it.

J. L. HOGAN, JR.: You state that you use very loose couplings at the receiver, and that the tuning is much better than can be had with feebly damped oscillations of the type produced by quenched spark transmitters. Perhaps you will recollect that it has often been contended that if quite persistent waves were used one might secure all the resonance benefits of sustained wave transmission. If I recollect correctly, this was your own position formerly.

DR. DE FOREST: It was, but my recent work has forced me to change my opinion in that respect. We are able to secure tuning conditions that I would have considered impossible with the best quenched spark senders. I feel certain that with the sustained oscillations you can secure better tuning.

J. L. HOGAN, JR.: Have you made any measurements which would indicate that the attenuation term in the Austin-Cohen transmission equation should have a different value for sustained than for damped waves, or that there should be a factor included which varies with the transmitter decrement?

DR. DE FOREST: We have secured no data in that direction as yet. I expect to attack the reflection and interference problem more exhaustively first.

It may be of interest to those present to know that we have shipped a 30 kilowatt set to the Government station at Arlington, Virginia. For such sets we require an antenna capacity of 0.01 microfarad. This set should be installed within a few weeks. Personally I anticipate considerable absorption in the towers. They are too near together. By the first of the new year we will have a 60 kilowatt arc in operation. This type of arc brings with it new problems of cooling, etc. The general construction of our arcs is shown in Figure 15. Water cooling is accomplished by the water jackets and pipes at W. The diameter of the carbon in the 12 kilowatt arcs is 1 inch, and this may rise to 4 inches in the 60 kilowatt arcs.

WIRELESS TELEPHONY

H[enry] J. Round

WIRELESS TELEPHONY

By H. J. Round.

DURING 1913 and 1914 Wireless Telephony for moderate distances has at last progressed to the practical stage, and several distinct methods have been developed by different workers.

Of these, the Japanese TYK system, the American Janke system, Ditcham's quenched spark system, and the reaction valve system are those most worthy of note.

TYK System.—The TYK system is one, the chief value of which is practical simplicity; but unfortunately demonstrations witnessed by the writer indicate a very poor quality of speech. Certainly in these demonstrations, which were given in England by a Japanese expert, certain parts of the apparatus, notably the microphone, were quite unsuitable for the circuits used, but this fact the demonstrator did not seem to recognise.

Briefly, the system as used consists of a 500-volt arc between points of burnt magnetite and brass shunted by a circuit with rather large capacity and small inductance.

This circuit is closely coupled to the aerial system, in which a current of about 1 ampère is induced.

A heavy current microphone placed in series with the aerial serves to impress upon the current the variations of the voice.

The inventor, Torikato, is of opinion that the result produced is a quenched spark of spark frequency beyond the limit of audibility.

A system of regulation of arc-length, and an arc striker similar in principle to most arc lamp regulators, is used. Very occasional hand regulation is required.

A "Perikon" detector is used for reception. It is claimed that the set when used by inexpert people has a five-mile minimum range, and that distances up to seventy miles have been worked by experts.

Fig. 1 (*facing page* 574) shows the complete Wireless Telephone set, except for the small 500-volt generator.

Fig. 2 (*facing page* 580) illustrates Torikato speaking on his wireless telephone.

A number of handles are provided for adjustment, none of which seem to make much difference—owing, apparently, to the high damping of all circuits; but for ordinary use this is a distinct advantage.

As mentioned before, the speech quality is very poor, certainly not so good as that given by an ordinary telephone line; but no doubt improvement could be made in this direction.

Altogether Torikato has met the important requirement of simplicity, but at the expense of the first essential in a telephone—good speech quality.

Recent reports from operators on liners sailing in the neighbourhood of Japan who have overheard the Japanese working the system indicate that improvements have taken place and that the speech quality has been bettered very considerably.

Janke System.—An American variation of the Poulsen arc is being used for telephony. The Poulsen arc has a very slow starting condition, due usually to the initial presence of air in the arc chamber.

Janke overcomes this difficulty by making his arc in liquid alcohol. An arc length regulator, similar to that of the TYK system, is used; but is not an absolute necessity.

Two to three ampères can be obtained in the aerial, and Janke has developed a special water-cooled multiple microphone for handling the current.

This arc acts very similarly to the Poulsen arc, being, if anything, more variable in frequency. Small condenser and large inductances are necessary, as with the other arc. It is not quite silent: a gentle bubbling can be heard most of the time at the receiving end. This, however, does not interfere much with the speech. The quality of the latter is good—far better than the TYK.

This arc seems to be very inefficient; since in tests witnessed by the writer $1\frac{1}{4}$ kilowatts input only gave between 2 and 3 ampères in the aerial with the microphone short-circuited.

Various quenched spark systems have also been tried, notably

that of Ditcham; but this, like the TYK, did not give good speech quality.

It is rather doubtful whether in any quenched spark system the primary circuit should be coupled direct to the aerial. It would seem to be better to couple the primary circuit to a closed circuit, and then couple this loosely to the aerial.

The reason for this is that if the microphone be inserted in series with the aerial, then, when the latter is coupled directly to the quenched primary circuit, the microphone is called upon to vary the current under two conditions—

(1) During the occurrence of the spark, when the apparent resistance of the aerial is high;

(2) During the period when the spark has stopped and the aerial is oscillating freely:

whereas if an intermediate circuit with loose coupling were used the aerial would be almost free the whole time.

High-frequency alternator systems have been used ever since the first trials of Fessenden, nearly ten years ago, but even now they are only to be considered as experiments, owing to their prohibitive cost, their low frequency, and consequently excessively long wave-length, and the difficulty of speed regulation.

Towards the end of 1913 the writer received, at Marconi House, very fair speech from Berlin, but the results were far from practical. A power of six kilowatts was used at the transmitting end, and about twenty microphones connected together. Also a very powerful man's voice was used for shouting, and at the receiving end very great magnification was required.

Better communication would have been obtained by telegraphing with a ½-kw. spark set.

In France, Colin and Jeance have done considerable work on an arc telephone, on occasions using the new Marzi microphone (which from all reports seems to show great promise).

The chief points about the arc set used by these experimenters are:

(1) That no magnetic field is used on the arc.

(2) Very small electrodes, in the form of thin discs, are used.

(3) A gaseous mixture of acetylene and hydrogen is used, which adjusts the wear of the carbon electrodes to zero.

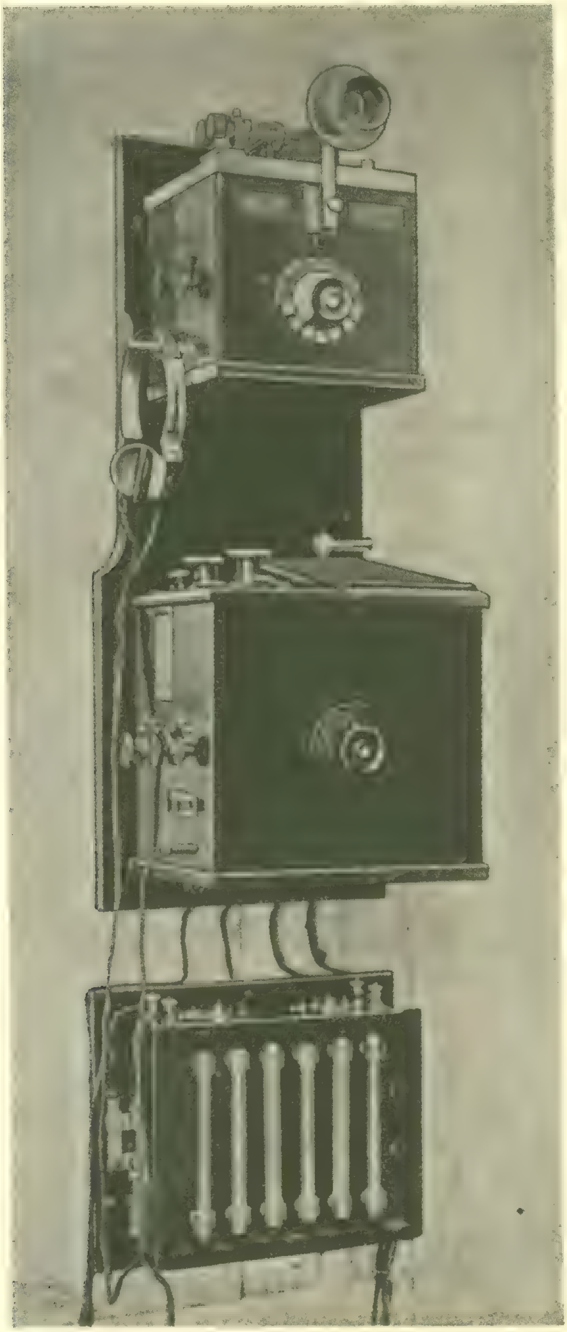


Figure 1.
Wireless Telephone Set.
T Y K System.

[*To face page* 574

These three points were embodied in apparatus constructed by Mr. Prince and the writer, seven years ago—except that in the third case a mixture of alcohol and petrol was used instead of acetylene and hydrogen.

Marzi's microphone, mentioned above, works on a rather surprising principle.

To prevent the microphone cell heating, the carbon granules are continually replaced—in fact, they move past the electrodes in a continuous stream. This microphone is said to be able to handle a current of 4 to 5 ampères, and the speech quality to be good.

This means that there has been produced a microphone capable of handling ten times the power of any single cell microphone in use at present without resort to liquid devices.

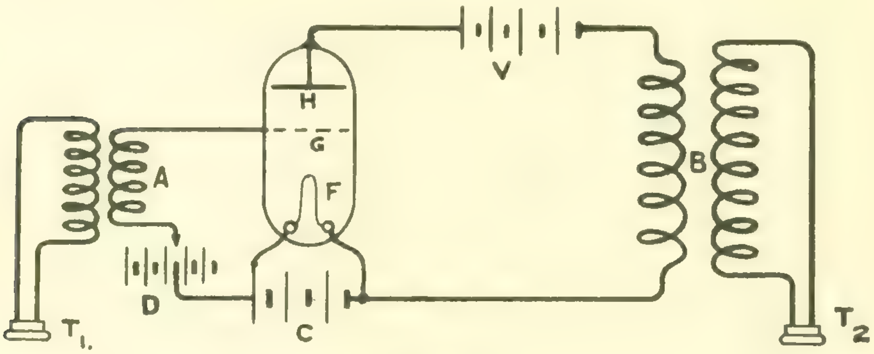


Fig. 3.

Reaction Vacuum Tube Methods.—In 1904 Fleming introduced the valve to wireless telegraphy, and in 1906 De Forest the "audion."

These instruments were constructionally identical, and were both, in their original form, rectifiers pure and simple. Any difference was possibly due to slight differences in the circuits used, perhaps to differences in vacuum, and to the now well-known fact that the valve has more than one rectifying point.

Afterwards De Forest introduced the "grid" or third electrode to the valve.

Very little seems to have been done with the "grid" tube from 1906 to 1913, when the introduction of the Lieben tube as a definite magnifier for telephone signals revived the whole question. De Forest had in the meantime dropped his English

patents, possibly on account of failure to recognise their importance.

The Lieben tube had obviously been developed quite independently of the modified audion, and had distinct properties of its own; but the underlying principle of magnification seems to be the same.

Incidentally, the writer has determined that to obtain magnification it is not at all necessary to place the grid inside the tube, although for most purposes it seems to be more satisfactory thus.

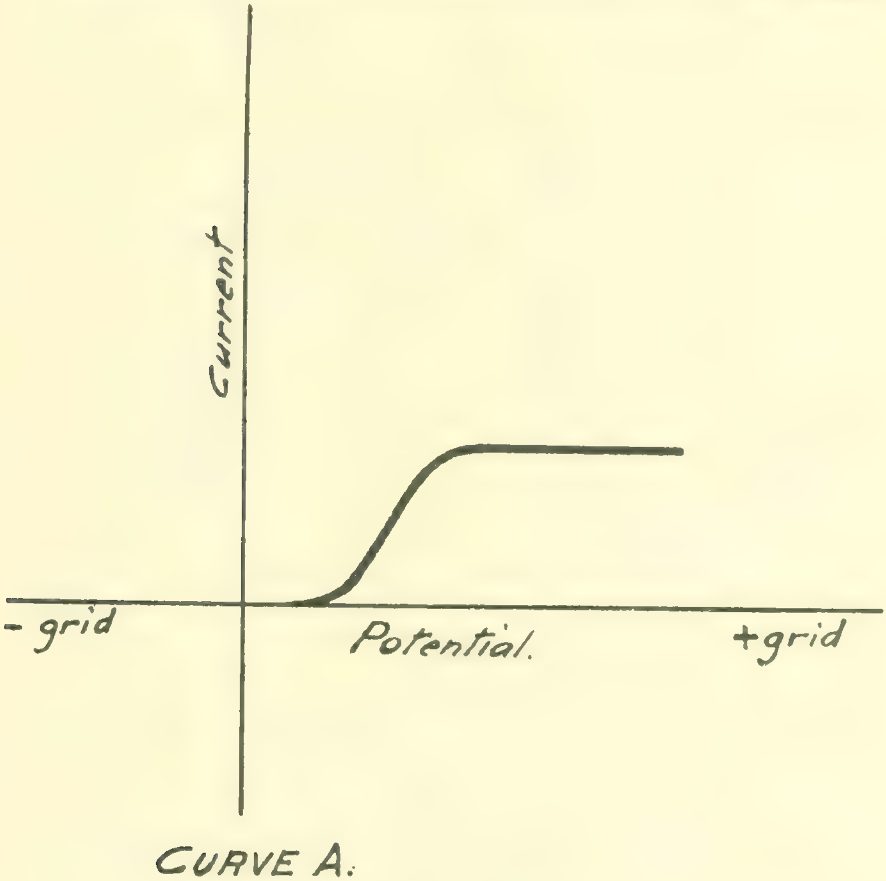


Fig. 4 (*a*).

The grid " audion " circuit interests us very little at present in telephony, but a short description of the action of the tubes as magnifiers will lead up to the method of producing oscillations by means of them.

The vacuum tube F.G.H. (Fig 3) has a filament F, a "grid" G, usually consisting of a plate with holes in it, and an anode H. The filament F is first rendered incandescent by a suitable battery C. To G and F are connected the terminals of a transformer A, a small potential-changing battery D being inserted to vary the potential of G.

The terminals of a transformer B are connected through a

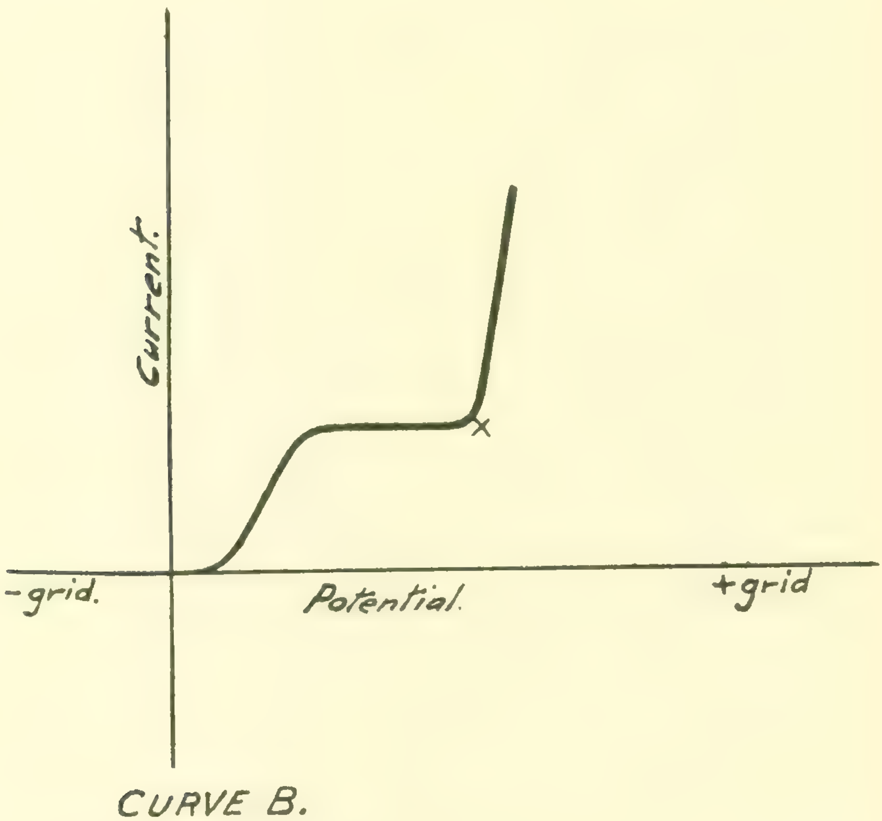


Fig. 4 (*b*).

comparatively high potential battery V to the anode H and the filament F.

If T1 and T2 represent two telephones, then any sound conveyed to T1 will be emitted by T2 considerably magnified.

The frequency which can be magnified depends merely upon the design of the transformers A and B.

A rough theory of the action is as follows.

Filament F when hot enough projects negative corpuscles or electrons from its surface.

For the present consider anode H disconnected from the high-voltage battery; then if G is made negative with respect to all parts of the filament F, all electrons which approach it are repelled, and no current can flow between F and G.

If G is gradually made positive and then more positive the current flows and increases, and finally a saturation is reached. Curve A, Fig. 4 (*a*), illustrates this.

Now if the gas in the tube has been completely removed no further action takes place; the whole question remains one of the flow of electrons—however high the voltage be made—unless one except the possible production of X-rays at high voltages. If, however, some gas is present, then curve B, Fig. 4 (*b*), is obtained—a glow appearing in the tube at the point X on the curve.

This glow, indicating ionisation, is produced by the electrons during their fall to the grid gathering velocity and breaking up the gas molecules. Each electron released from the filament thus becomes the cause of other electrons being freed from the gas molecules, and these at once begin falling through the potential gradient, gathering velocity and liberating more electrons.

If the gas is too dense this may result in an ionised gas, in which the amount of the ionisation is independent of the original number of electrons; but by a proper adjustment of the vacuum, the dimensions, and the anode voltage, a condition can be arrived at in which the amount of ionisation is a function of the original number of electrons liberated.

The point X is very possibly the point De Forest was using in the first audion; and as the valve used at this point is distinctly a lower resistance device than when used at the Fleming point, he would probably have obtained better results by the use of circuits such as those adapted to the electrolytic detector, which, however, are not at all suitable for the Fleming valve.

When the third electrode is introduced, the question becomes slightly different.

Suppose H, the anode, is connected up as in Fig. 3 and made sufficiently positive, so that the whole tube would be glowing (that is past the point X, Curve B, Fig. 4, *b*) but for the presence of the grid, G.

Now starting with G strongly negative, notwithstanding the anode H being highly positive, the electrons cannot get through the grid holes because the negative grid is nearest to them. At a very small negative value of G a few electrons can get through the holes, and will fall to H, and the number that will get through will rapidly increase until G is zero potential: the current to H then being equal to the value that it would be if G was absent. Afterwards, as G becomes positive, the current will decrease, because G will absorb some electrons.

The amount of ionisation taking place will vary with the number of electrons that can creep through G.

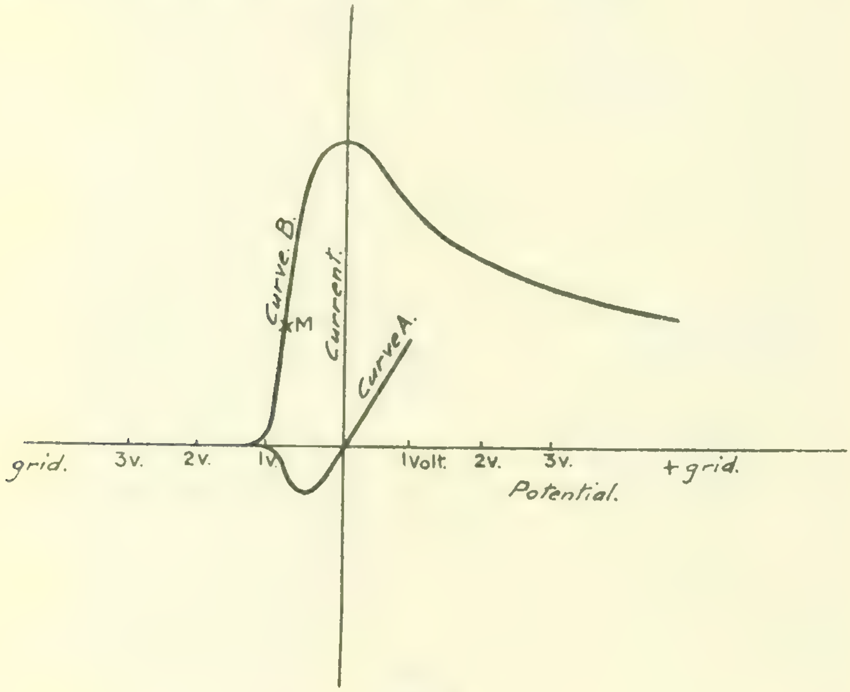


Fig. 5.

Thus a very small potential change on G will make a large current variation flowing to H, because of the consecutive ionisation started by these electrons which creep through.

The characteristic curves for a sensitive tube are given in Fig. 5. These are taken simultaneously.

Curve A represents the current to the grid.
,, B ,, ,, ,, ,, ,, anode.

The point M on Curve B and its accompanying point on Curve A is the chief magnifying point.

The maximum practical magnification is given by a tube by careful adjustment of the vacuum to the anode voltage and to the filament brilliancy.

The magnification is extremely difficult to estimate; various measurements giving anything between 5 and 25 times for tubes constructed by the writer.

The above rough theory is very imperfect and certainly does not explain away various other properties of these tubes; but, as an indication of why there is magnification at all, it is very useful.

Messner, in 1913, suggested the use of the Lieben Tube for the production of continuous oscillations, by allowing the two transformers, A and B of Fig. 3, to react upon one another, and by inserting in the circuits condensers to give them a definite natural period; and he succeeded in producing 8 watts of high frequency alternating current by this means.

The tubes apparently only lasted about 10 minutes at this power, owing to disintegration of the filament.

This reaction method has an exact analogy in the singing microphone telephone. As is well known, any telephone receiver when held opposite its own microphone (providing the line is short in length) will give a musical note, because the microphone is a magnifier. A Brown relay, if connected back on itself, will also sing violently.

The writer has so developed these two properties of the valve during the last eighteen months as to make a fairly practical telephone system.

The reaction valve is used for producing the transmitting oscillations; and, the energy employed being small, the magnifying valve is used for magnifying the received result up to a practical loudness.

It was very soon found out that the ordinary magnifying valve was, in practice, quite useless for the production of oscillations owing to the filament disintegration, and the present oscillating valve has, at the most, a magnification of 3, but it will easily give current up to one ampère in the aerial without serious filament wear.

The first distance tests were carried out in Italy by the writer between two Italian cruisers in the presence of the Duke of Abruzzi and Mr. Marconi.

Figure 2.

T Y K System.

Torikato speaking on his Wireless Telephone.

[To face page 580

It was at once found that ridiculously small aerial currents, such as ·2 ampères, were sufficient to enable speech to be transmitted 70 kilometres, this high efficiency being due to the absolutely silent and constant character of the oscillations produced and to the consequent ability to magnify at the receiving end.

The question of magnification at the receiving end is one well worth a little consideration.

The extraordinary sensitiveness for weak signals of the "heterodyne" indicated to the writer that the crystal detector is approximately obeying the law indicated by its direct current characteristic, and that, owing to the bend in the curve, rectifying efficiency falls off rapidly with reduction of applied signal voltage.

Consequently, a crystal detector is more efficient for weak signals from a spark station than equal powered signals from an arc station, because, particularly with short waves, the maximum voltage of the sparks is much higher than the maximum voltage of the continuous wave.

This at once reduces the efficiency of continuous wave telephony, as the "heterodyne" cannot possibly be used.

But by the now simple process of magnifying the received oscillations before they reach the rectifier, this lack of efficiency is partly overcome. Of course, this magnification would also further improve spark telephony, but no spark telephony yet produced is sufficiently free from horrid noises to allow of any magnification.

In addition to this a great improvement is obtained by utilising a principle due to Mr. C. S. Franklin. The circuit with the magnified energy in it is allowed to react back on the receiving aerial so that the whole system has an effective damping only slightly greater than zero. The result is an additional magnification, and the total result is that speech or spark signals, quite inaudible with a crystal-receiver, are received strongly and with great selectivity due to the extremely low effective damping of the receiving system.

A development of the sets used in Italy is shown facing page 550.

The set delivers ·6 ampères to the aerial, the microphone usually being inserted in series with this aerial. The sets are guaranteed for 50 kilometres between ships at sea. The set

can be further extended to give 1 ampère in the aerial with an estimated range at sea between moderate sized ship aerials of 100 miles.

500 volts and 15 milliampères are required to produce ·6 ampères in an average aerial.

The writer had already obtained 3 ampères in an aerial by this method—the voltage required is 2,000 and the milliampères 100, and as this voltage is rather excessive, an attempt is being made to reduce it and use more current, but heavier current tubes usually result in greater filament wear.

No microphone troubles have yet appeared, as, owing to the magnifying power of these tubes, it is not at all necessary to place the microphones in the aerial.

Incidentally, these combined transmitter and receiver sets are useful for telegraphy, as the receiver is a "self heterodyne" by slightly altering the adjustment. The telegraphic range is twice the telephone range.

A good many faults can still be found with this telephone. The tuning of both transmitter and receiver is a little too fine. Also the starting condition may be slow in cold weather. These faults will shortly be remedied.

A selective call system, due to Mr. Dobell and Commander Ryan, was being tried on these sets, but, unfortunately, the European trouble has practically stopped all possibilities of experimenting.

SOME RECENT DEVELOPMENTS IN THE AUDION RECEIVER

Edwin H[oward] Armstrong

SOME RECENT DEVELOPMENTS IN THE AUDION RECEIVER[1]

BY

EDWIN H. ARMSTRONG

THE AUDION AS DETECTOR AND AMPLIFIER

The fundamental operating characteristic of the audion is the relation between the wing current and the potential of the grid with respect to the filament—say the negative terminal of the filament. Such a characteristic is shown in Figure 1, and

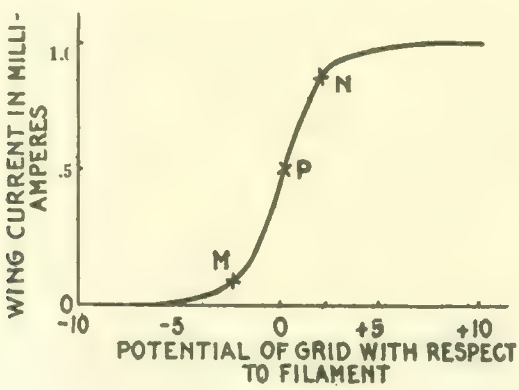


FIGURE 1

from it we see that a positive charge placed on the grid produces an increase in the wing current, and that a negative charge placed on the grid produces a decrease in the wing current. When the audion is used as an amplifier, and an alternating e. m. f. is impressed between the grid and the filament, the continuous current of the wing circuit will be varied in accordance

[1] Delivered before The Institute of Radio Engineers, New York, March 3, 1915, and before the Boston Section, April 29, 1915.

(The introductory material of this paper was originally submitted as a discussion by letter on Haraden Pratt's paper, "Long Range Reception with Combined Crystal Rectifier and Audion Amplifier." The first six figures have been kindly lent by the "Electrical World"; the remaining figures and text are herewith published for the first time.)

with the characteristic of Figure 1, producing on the continuous current a superimposed a. c. wave in phase with and of the same frequency as the impressed e. m. f. Diagrammatically this action is shown in Figure 2.

The action of the audion as a detector of radio frequency oscillations is very different from its action as a simple amplifier. Some form of connection must be used, such that the effect of a

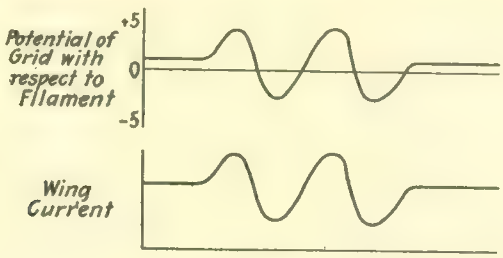


FIGURE 2

group of radio frequency oscillations in the grid circuit of the audion is translated into a single audio frequency variation of the current in the telephones. The usual method is to make use of the valve action between the hot and cold electrodes at low pressures, and the connection used to do this is shown in Figure 3. In this method of connection there are two distinct

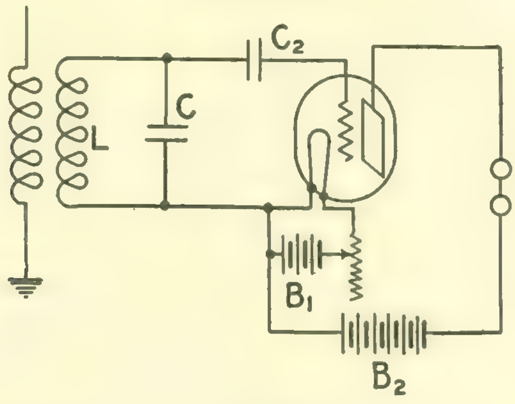


FIGURE 3

actions; one rectifying and the other amplifying. The closed oscillation circuit: LC, filament, grid, and condenser C_2, behaves exactly as a Fleming valve receiver, the incoming oscillations being rectified between the grid and filament and the rectified current being used to charge the condenser C_2 (the side connected to the grid being of course negative). The negatively

charged grid then exerts a relay action on the wing current, decreasing it; the wing current returning to its normal value as the charge in the grid condenser leaks off by way of the grid and the grid resumes its normal potential. If the audion is properly constructed, the relay action results in an amplification of the energy available for use in the telephones over that which would be available in a simple rectifier. Figure 4 indicates the features of the valve method of detection.

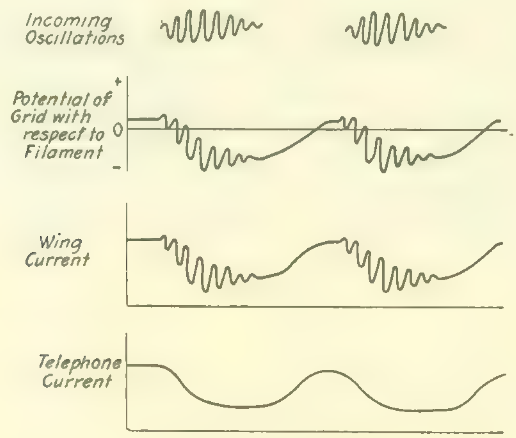


FIGURE 4

Working in conjunction with Professor Morecroft, I have recently secured oscillograms which confirm the explanations already advanced and these oscillograms and the means by which they were obtained are herewith shown in Figures 5, 6 and 7.

FIGURE 5

It will be seen, therefore, that using the audion as a detector of radio frequency oscillations, it has been shown that in addition to operating as a rectifier it simultaneously acts as a

FIGURE 6

repeater of the radio frequencies; so that oscillations in the grid circuit set up oscillations of similar character in the wing circuit of the audion. In the ordinary detector system no use

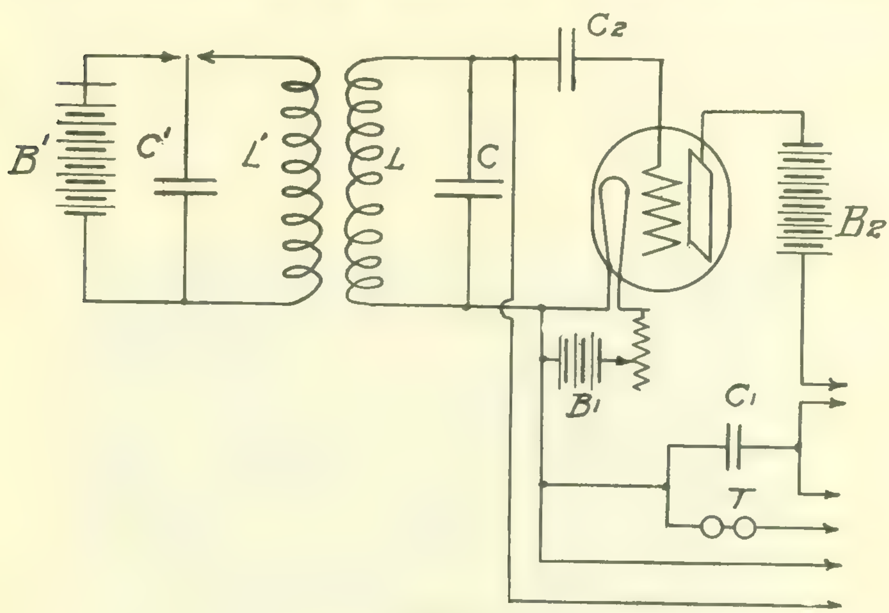


FIGURE 7

is made of the repeating action, and it is the purpose of the present paper to show that it may be turned to account to produce improvements in the reception of signals which com-

pletely overshadow any of the particular advantages of the audion when used as a simple detector. The ordinary detector circuit is illustrated by Figure 3 and the phenomena present therein may be summed up diagrammatically by the curves of Figure 4. It will be seen from these that the radio frequency oscillations present in the wing circuit of Figure 3 with the ordinary audion are necessarily small and also that they are of no value in producing a response in the telephones; but by providing means for increasing their amplitude and means for utilizing them to reinforce the oscillations of the grid circuit, it becomes possible to produce some very remarkable results.

REINFORCEMENT OF RADIO FREQUENCY OSCILLATIONS BY THE AUDION

There are two ways of reinforcing the oscillations of the grid circuit by means of those in the wing circuit. The simplest way perhaps is to couple the two circuits together in the manner shown in Figure 8. This is essentially the same as Figure 3, but

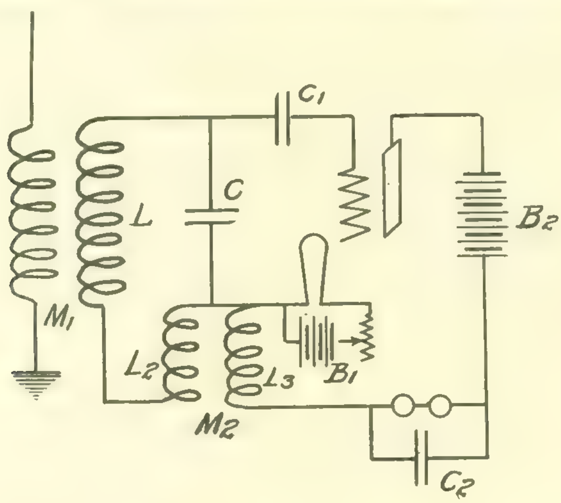


FIGURE 8

modified by the introduction of the inductively coupled coils L_2 and L_3 in the grid and wing circuits respectively and by the condenser C_2 which forms a path of low impedance across the telephones for the radio frequencies. In such a system, incoming signals set up oscillations in the grid circuit which repeat into the wing circuit producing variations in the continuous current, the energy of which is supplied by the battery B_2. By means of the coupling M_2, some of this energy of the wing oscillations is transferred back to the grid circuit, and the

amplitude of the grid oscillations thereby increased. The amplified grid oscillations then react on the wing circuit by means of the grid to produce larger variations in the wing current, thus still further reinforcing the oscillations of the system. Simultaneously with this procedure the regular detecting action goes on; the condenser C_1 is charged in the usual way, but accumulates a charge which is proportional, not to the original signal strength but to the final amplitude of the oscillations in the grid circuit. The result is an increased response in the telephone proportional to the energy amplification of the original oscillations in the grid circuit. It will be observed from the operating characteristic (the relation between grid potential and wing current), that the amplitude of the variation in the wing current is directly dependent on the variation of the grid potential. This indicates that the grid circuit should be made up of large inductance and small capacity to obtain the maximum voltage which it is possible to impress on the grid. For moderate wave lengths the tuning condenser C of the grid circuit may be omitted altogether and the capacity of the audion alone used to tune the circuit. For long wave lengths, the distributed capacity of the grid circuit inductance becomes so high with respect to the capacity of the audion that better results are obtained by the use of a tuning condenser to fix definitely the points of maximum potential difference across the grid and filament of the audion.

In the second method of reinforcing the oscillations of the grid circuit the wing circuit of the audion is tuned by means of an inductance introduced as shown by Figure 9. This differs

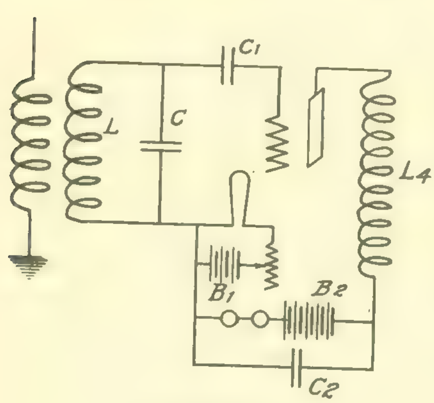


FIGURE 9

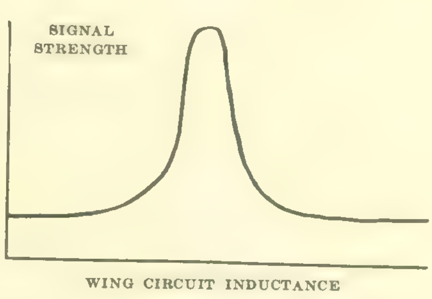


FIGURE 10

from the ordinary detector circuit of Figure 3 by the addition of the coil L_4 and the condenser C_2. The manner in which the

grid oscillations are amplified may best be understood by the following analysis. With no oscillations in the system, the potential difference between filament and wing will be approximately the voltage of the battery B_2, but when oscillations are set up in the grid circuit, causing radio frequency variations of the wing current, the potential of the wing with respect to the filament varies as the reactance voltage of the wing inductance alternately adds to and subtracts from the voltage of the battery. When a negative capacity charge is placed on the grid, the wing current will be reduced and the direction of the reactance voltage of the wing inductance will therefore be the same as the voltage of the battery B_2. The reactance voltage will therefore add to the battery voltage and the difference of potential between wing and filament and also between wing and grid will be increased. Similarly when a positive charge is placed on the grid the wing current is increased and the reactance voltage of the wing inductance opposes the battery voltage, producing a decrease in the potential difference between grid and wing. Hence, supposing a negative capacity charge is placed on the grid, the tendency of the corresponding increase in the potential of the wing with respect to the grid will be to draw more electrons out on the grid, thereby increasing the charge in the condenser formed by the wing and grid, the energy for supplying this charge being drawn from the wing inductance as the wing current decreases. The increased negative charge on the grid tends to produce a still further decrease in the wing current and a further discharge of energy from the wing inductance into the grid circuit. On the other hand, when a positive charge is placed on the grid, the potential difference between grid and wing is reduced and some of the energy stored in the capacity formed by them is given back to the wing inductance. During this part of the cycle, electrons are being drawn into the grid from the surrounding space to charge the grid condenser in accordance with the well known valve action, and this, in effect, is a conduction current, so that a withdrawal of energy from the circuit takes place. In spite of this withdrawal of energy, however, a well defined resonance phenomena between the audion capacity and the wing inductance is to be expected and in the reception of signals such is found to be the case. When the wing inductance is properly adjusted at the resonance frequency, energy from the wing circuit is transferred freely to the grid circuit and oscillations build up therein and are rectified in the usual way.

A curve showing the general relation between signal strength and value of wing inductance is shown in Figure 10, the circuits used being those of Figure 9. As the capacity of the audion is the main means of transferring energy from the wing to the grid circuit, best results are obtained when the condenser C is very small. On account of the very small capacity of the audion, the effectiveness of this method of tuning is more pronounced at the higher frequencies, but by the use of a shunt condenser across the inductance of the wing circuit very good amplification is secured on frequencies as low as 30,000 cycles (10,000 meters wave length). The best results, however, are obtained with some combination of coupling and wing circuit tuning, as il-

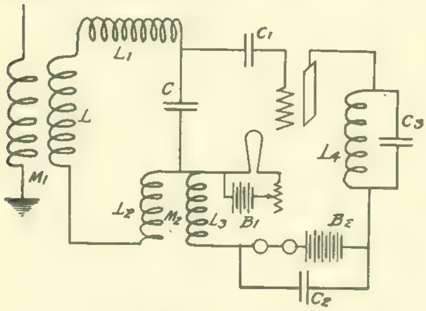


FIGURE 11

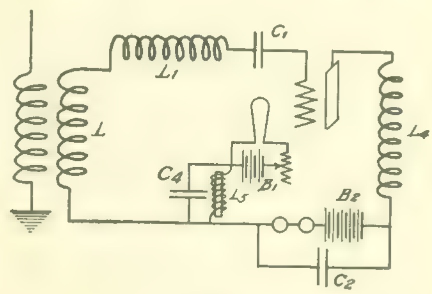


FIGURE 12

lustrated in Figure 11. Other methods of coupling may be employed between the grid and wing circuits, electrostatic and direct magnetic couplings being illustrated in Figures 12 and 13. The arrangement of Figure 13 operates in the same way as the system with the two coil coupling; but the electrostatic coupling

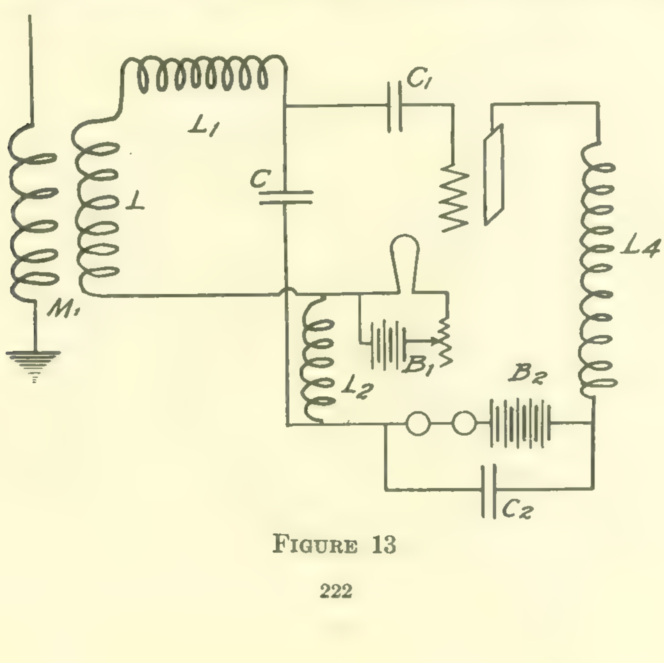


FIGURE 13

of Figure 12 works in an odd way. It is necessary, in this connection, to complete the wing circuit for the continuous current of the battery and this is done by shunting the coupling condenser C_4 by a coil of high inductance. The continuous current of the wing circuit flows thru this coil and C_4 provides a path of low impedance around this coil for the radio frequency oscillations of both grid and wing circuits. When a positive charge is placed on the grid, an increase in the wing current results, the alternating component of the wing current charging the condenser C_4 and the sum of the currents passing thru C_4 and L_4 equalling the current thru the audion. When a negative charge is placed on the grid the current thru the audion is reduced and the inductance L_5 discharged into the condenser shunted across it, charging it in the opposite way to that caused by the increase in the wing current. In both cases, C_4 then discharges thru the grid circuit reinforcing the oscillations therein.

AUDIO FREQUENCY AMPLIFICATION

It is possible to combine with any of these systems a system of audio frequency circuits which amplify the telephone current in exactly the same manner as the radio frequency oscillations are amplified, and such a system is shown in Figure 14. Here M_2

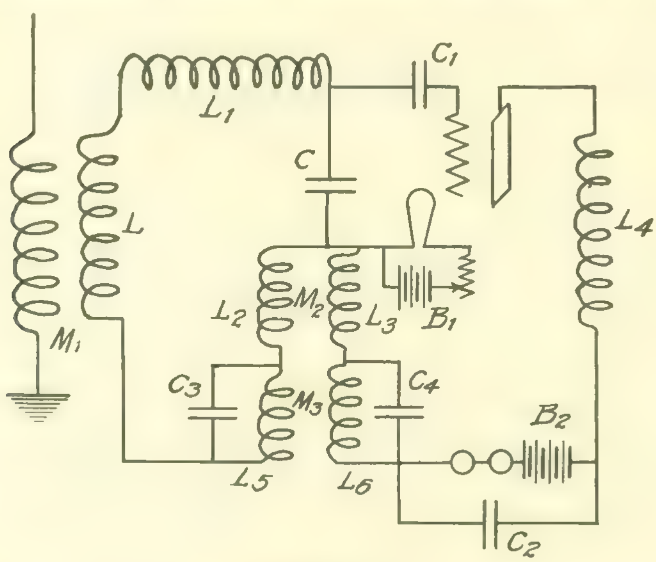


FIGURE 14

represents the coupling for the radio frequencies and the coils are of relatively small inductance. M_3 is the coupling for the audio frequencies, and the transformer is made up of coils having an inductance of the order of a henry or more. The condensers C_3 and

C_4 have the double purpose of tuning M_3 to the audio frequency, and of by-passing the radio frequencies. The total amplification of weak signals by this combination is about 100 times, with the ordinary audion bulb. On stronger signals, the amplification becomes smaller as the limit of the audion's response is reached.

THE AUDION AS A GENERATOR AND BEAT RECEIVER

Any repeater, which is also an energy amplifier, may be used to produce continuous oscillations by transferring part of the energy in the circuit containing the battery back to the controlling circuit to keep the latter continuously excited. By providing a close enough coupling between the grid and wing circuits, sufficient energy is supplied to the grid circuit to keep it in continuous oscillation, and as a consequence thereof oscillations of similar frequency exist in all parts of the system. The frequency of these oscillations is approximately that of the closed grid circuit if the tuning condenser of that circuit is large with respect to the capacity of the audion. If this capacity is small, then the wing circuit will exert a greater influence on the frequency of the system, and it will not approach that of the grid circuit so closely. When such a system of circuits is in oscillation, it has been found possible not only to receive continu-

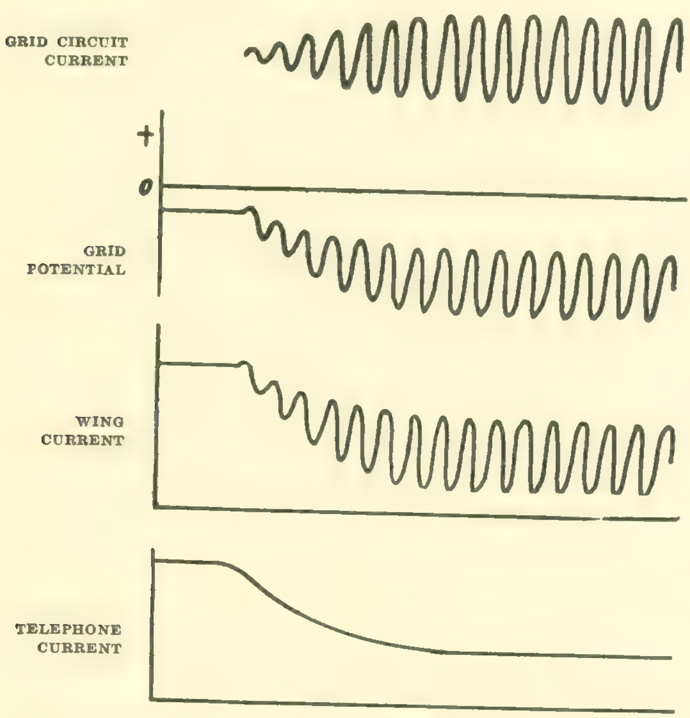


FIGURE 15

ous waves by means of the beat method but also very greatly to amplify them as well.

The phenomena involved may best be understood by reference to Figures 15 and 16, which show the relation between wing

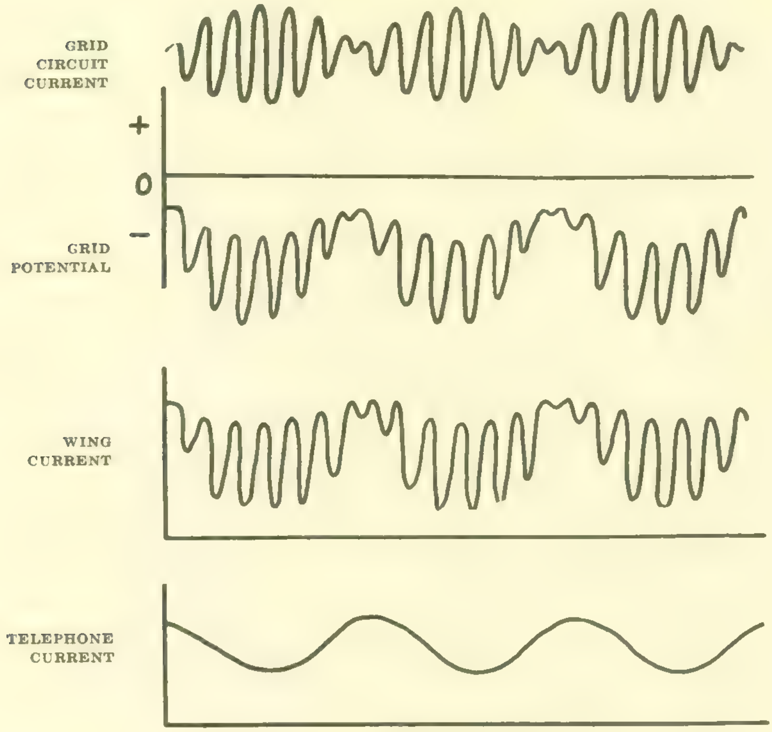


FIGURE 16

current and time at the beginning of oscillation. When the audion begins generating, the grid oscillations are continuously rectified to charge the grid condenser, and this charge continuously leaks off either by way of the grid or by means of a special high resistance placed in shunt with the condenser. As the negative charge builds up in the grid condenser, it decreases the average value of the continuous current component of the wing current and therefore limits the amplitude of the oscillations of the grid circuit until a point is finally reached where the rate at which electricity is supplied to the grid condenser is just equal to the rate at which it leaks off. Consider now the effect on the system of an incoming continuous wave having a frequency slightly different from the frequency of the local oscillations. The presence of the local oscillations will not in any way interfere with the amplifying powers of the system and the incoming oscillations will build up in exactly the same manner as for the

non-oscillating state but to a greater degree because of the closer grid and wing coupling. Simultaneously with the amplifying of the incoming wave, beats are produced between the local and the signalling currents, the effect being alternately to increase and decrease the amplitude of the oscillations in the system. From Figure 15 it will be apparent that when this steady state is reached an increase in the amplitude of the grid oscillations by any means whatever will increase the negative charge in the grid condenser, producing a decrease in the average value of the wing current and hence a decrease in the telephone current. On the other hand, a decrease in the amplitude of the oscillations will allow some of the negative charge in the grid condenser to leak off and thereby permit an increase in the telephone current. Hence, when incoming and local oscillations add up, the negative charge in the grid condenser is increased and a decrease in the telephone current results. When the two frequencies are opposed, some of the charge in the grid condenser leaks off and an increase in the telephone current occurs. The result is the production in the telephones of an alternating current having a frequency equal to the difference in the frequencies of the local and incoming oscillations and having the very important property of being almost simple harmonic. Figure 16 illustrates the characteristics of this method of reception. The complete phenomena may be summed up as follows. Incoming oscillations are simultaneously amplified and combined in the system to produce beats with a local oscillation continuously maintained by the audion. The radio frequency beats are then rectified by the audion to charge the grid and the grid condenser, and this charge varies the electron current to produce an amplifying action on the current in the telephones.

When the grid condenser is omitted, the beat phenomenon is slightly modified, and the audio frequency variation ot the telephone current is produced according to the asymmetric action outlined in a previous publication dealing with the operating features of the audion. The system is more sensitive with the grid condenser, but the same general result is obtained by either method of reception.

PECULIAR FEATURES OF OSCILLATION

Some very interesting features of operation accompany the production of oscillations in the system. Suppose the audion is not oscillating, and the grid and wing coupling is fairly weak. As this coupling is increased, the point at which oscillations

begin is indicated by a faint click in the telephones accompanied by a slight change in the character of the static. The oscillations produced are usually so high in frequency and constant in amplitude that they are entirely inaudible. As the coupling is still further increased, a rough note is heard in the telephones the pitch decreasing with increase of coupling. This note is produced by the breaking up of the oscillations into groups, and it occurs whenever electricity is supplied to the grid condenser at a greater rate than that at which it can leak off. The result is that the grid is periodically charged to a negative potential sufficient to cut off entirely the wing current, causing a stoppage of the local oscillations until the grid charge leaks off and the wing current re-establishes itself. The frequency of this interruption depends largely on the capacity of the grid condenser, the resistance of its leakage path, and the amplitude of the local oscillations; and it may be varied from several hundred down to one or less per second. This effect is sometimes troublesome in the reception of signals, especially with high vacuum tubes. It may be eliminated, however, by increasing the leak of the grid condenser by means of a high resistance shunt. The best coupling for receiving continuous waves lies somewhere between the point at which oscillations start and the point at which interruption begins, and can only be determined by trial. In this region, trouble is sometimes experienced by the appearance of a smooth musical note in the telephones. This occurs under certain critical conditions of coupling with the antenna when the grid circuit oscillates with two degrees of freedom. Two slightly different frequencies are therefore set up, producing beats which are rectified by the audion in the usual way. This effect is quite critical, and when it causes

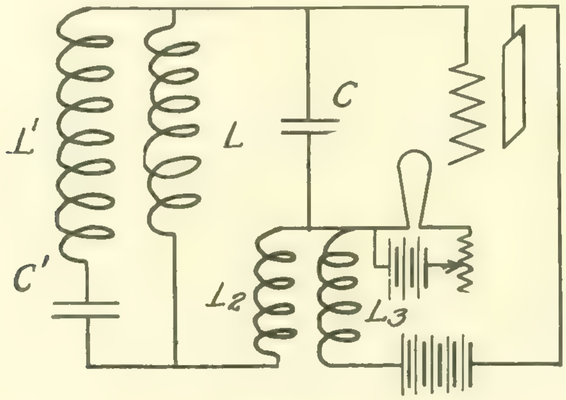


FIGURE 17

interference with signals, a slight readjustment of the circuits will usually make it disappear. It may, however, be made perfectly steady and reproduced at will by the system shown in Figure 17, where two grid circuits of different periods are provided. Two frequencies are therefore generated one having the frequency of the circuit LCL_2, and the other the frequency of the circuit $L'C'L_2C$. This arrangement may replace to advantage the ordinary buzzer for producing groups of oscillations. The foregoing explanations refer to the audion only when it is used as an electron relay.* When there is an appreciable amount of gas, in the tube in the ionized state, disturbances of an entirely different character occur.

AUDIO FREQUENCY TUNING

One of the very important advantages of the receiver when used for continuous waves is that the alternating current produced in the telephones is almost a pure sine wave. Only when the audio frequency is simple harmonic can selectivity be obtained by tuning the telephone circuit. A distorted wave such as that produced by spark signals possesses many harmonics and as each may be picked out by the tuned telephone circuit there is little chance of separating two spark signals by audio frequency tuning. With continuous waves, however, the pure wave produced by the beat method of reception makes it possible to obtain selectivity by the audio frequency tuning, resonance

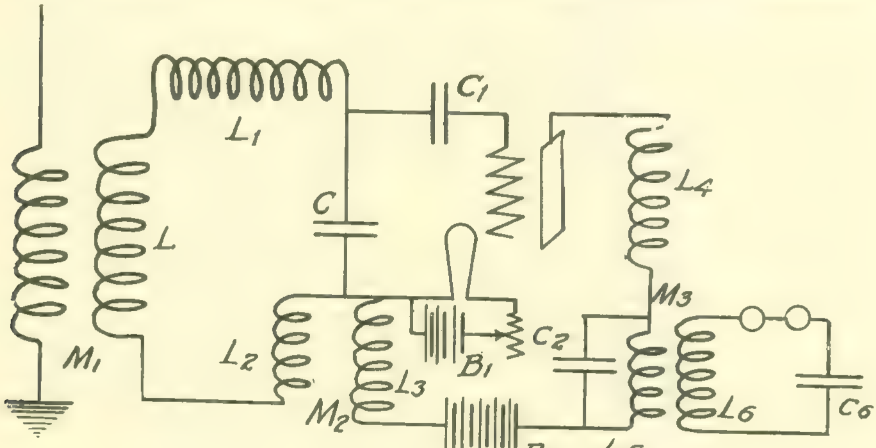


FIGURE 18

* "Electrical World," December 12, 1914; and also discussion in "London Electrician," between Reisz and de Forest on the difference between electron and gas relays. (February 6, 1914, page 726; March 13, 1914, page 956; June 12, 1914, page 402; July 3, 1914, page 538; and July 31, 1914, page 702.—EDITOR.)

being fully as sharp as in the radio frequency circuits. Two methods of audio frequency tuning are shown in Figures 18 and 19. In Figure 18, the telephone is inductively connected to the wing circuit of the audion by means of a transformer the secondary of which includes besides the telephone a tuning condenser.

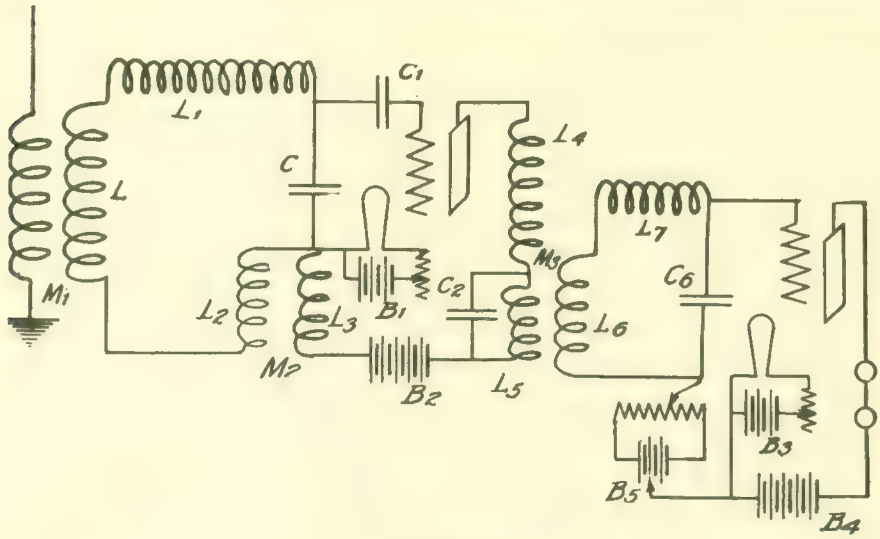


FIGURE 19

In this connection, the telephone, with a resistance of many thousand ohms, is placed directly in the tuned audio frequency circuit, and hence for good tuning the inductance of the coil L_6 must be made extremely large to secure the necessary ratio of the reactance of L_5 to the resistance of the circuit. This disadvantage is overcome in the system of Figure 19 by removing the telephones from the audio frequency circuit, and using the latter to operate a second audion. The telephones may then be placed in the wing circuit of this audion without adding appreciably to the damping of the circuit. The tuning of the circuit L_6C_6 may therefore be made very sharp with reasonable values of inductance simply by keeping the resistance low. In this case considerable amplification is obtained by the use of resonance in the transformer M_3 to increase the voltage impressed on the grid of the second audion. The great advantage of this kind of tuning is shown by the following example. Suppose the incoming signal has a frequency of 50,000 cycles, and the local frequency is 49,000 cycles. The differential frequency is 1,000, and the audio frequency circuit is tuned accordingly. An interfering wave 1 per cent. shorter than the signalling wave, or 49,500 cycles, will produce an audio frequency of 500 cycles per second,

which will not appear at all in the wing circuit of the second audion unless it is many times stronger than the 1,000 cycle signal. This combination of radio and audio frequency tuning is too selective for use at the present time even when the sending station is equipped with an alternator, as the slight changes in frequency of the radiated wave produce changes in the beat frequency of the receiver which carry it out of range for the sharply tuned audio frequency circuit. A disadvantage of this method of tuning is that atmospheric disturbances produce a musical note due to shock excitation of the audio frequency system. Very loose coupling with the wing circuit of the first audion is a partial remedy for this. There are times, however, when interference is more troublesome than static and in such cases the method may be used to great advantages. If desired, both radio and audio frequency tuning can be carried out in the same audion as indicated in Figure 14. This combination is apt to be somewhat troublesome to operate as a cumulative amplification is obtained in the audio frequency as well as in the radio frequency system.

CASCADE SYSTEMS

Where a greater amplification than can be obtained with one audion is required, cascade working of the radio frequency systems may be resorted to by coupling together two or more audion systems, each connected as already described, in the manner indicated in Figure 19. The incoming oscillations in the first audion system are amplified in the usual manner and

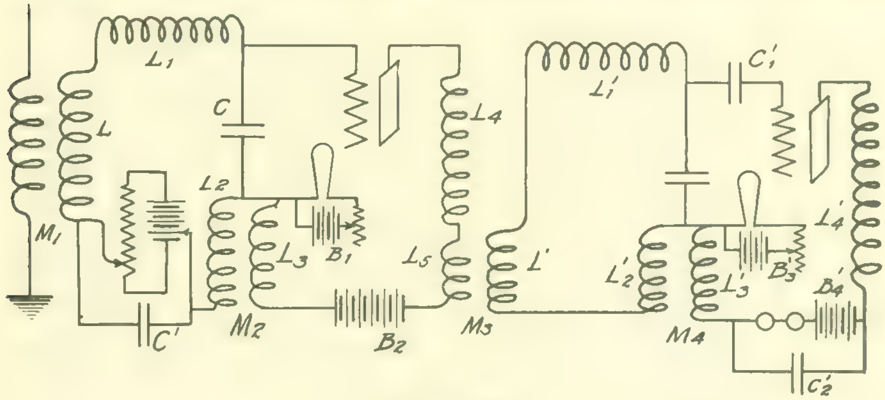


FIGURE 20

set up oscillations in the second system by means of the coupling M_3 (See Figure 20). The oscillations initially set up in the second system are again amplified, and then rectified in the second audion to produce audible response in the telephones.

For the reception of spark signals, considerable adjustment is required to get the best results without causing one or the other or both of the systems to generate oscillations. It will be found that after the first circuit is adjusted to the point of oscillation and the second is coupled with it, the strength of signal in the first system will be reduced owing to the withdrawal of energy from it by the second system. The signals may then be again brought up in strength by increasing the coupling between the grid and wing circuits of the first audion until the appearance of the local oscillations indicates that the limit of amplification has been reached. By careful adjustment about a thousand times amplification and very sharp tuning can be obtained with two steps.

For continuous wave reception, there are several methods of operating cascade systems. It is possible to have either system generate oscillations, the other system acting simply as an amplifier or both systems may be made to generate in synchronism. It will generally be found that when both systems produce oscillations, beats will be produced, so that a continuous note is heard in the telephones; but by adjusting the frequency of one of the systems the pitch of this note will be reduced as the two systems approach synchronism, until finally at one or two hundred beats per second the two systems pull into step in much the same way as two alternators. The ability of the two systems to keep in step depends mainly on the value of the coupling between them, and the closer this is the better the two hold together. There is still another way of working this combination, and that is asynchronously. In this case beats are continuously produced in the system so that a continuous note is heard in the telephone, but the circuits may be so adjusted that the note is not loud enough to be troublesome or it may be tuned out of the telephone in the manner previously described. Incoming oscillations are combined in the system to produce beats with the beats already present so that a rather curious note is heard. Very good amplification is secured by this method though naturally the system is troublesome to operate.

It may be noted here that whenever a signal is too weak to read with one audion system and cascade operation becomes necessary, it is always better practice to use the cascade circuits for the radio frequencies, even if the regenerative circuits are not employed with each individual audion system. The frequency of the oscillations set up in the circuits by static are,

under normal conditions, the same as those of the incoming signal; and the static is therefore never amplified more than the signal. Usually it is amplified to a somewhat lesser extent, especially if regenerative circuits are employed. In the cascade systems used for audio frequencies, a different condition exists. It is ordinary practice to connect the different stages by means of transformers, and this leads to conditions which cause the system to produce greater amplifications of the higher frequencies. The rate of change of the wing current of the detecting audion produced by static corresponds to a very high frequency, and as such is invariably amplified to a greater extent than the signal.

There is a second method of receiving continuous oscillations which makes use of the generating feature of the audion, but does not employ the beat phenomena. The amplifying ratio of the audion depends more or less directly on the value of the wing current, and by varying this current periodically there will be a corresponding periodic change in the amplifying power of the audion. Hence an audion arranged to repeat a continuous wave under such conditions will produce in its wing circuit oscillations which vary periodically in amplitude, and which may therefore be received by a simple audion system. The first audion may be arranged to produce the necessary variation in its amplifying power in the manner indicated in Figure 21, which also

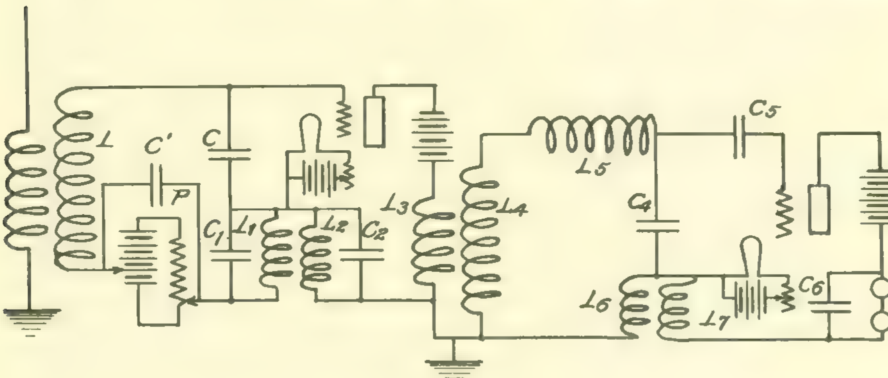


FIGURE 21

shows the complete circuits for carrying out this method of reception. Here $C_1L_1L_2C_2$ is an audio frequency system designed to produce audio frequency oscillations; and P is a potentiometer for adjusting the potential of the grid so that on the negative part of the oscillation in the wing circuit, the wing current is reduced practically to zero. The radio frequency

circuit $C'L\ C\ C_1$ is tuned to the oscillation frequency of the incoming wave. The radio frequency oscillations cannot be detected in the first audion system as the strong audio frequency current circulating in this system would produce a continuous note in the telephone receivers of such strength as to render inaudible all save very strong signals. By arranging to detect the oscillations in a second audion system coupled to the wing circuit of the first, interference of this sort is avoided; as the circuit $L_4\ C_4$ has a very high impedance for the audio frequency currents and the effect produced thru the magnetic coupling of L_3 and L_4 on the second system is negligible. The capacity current between these two coils thru the telephones to ground is, however, appreciable; and to avoid it it is advisable to ground their two adjacent ends as shown. The action of the system may be summed up as follows. The first audion system varies the amplitude of the incoming radio frequency oscillations at an audio frequency, and the second audion system amplifies and detects the radio frequency oscillations supplied to it by the first system. Diagrammatically, the phenomena occurring are as illustrated in Figure 22. The system gives about the same

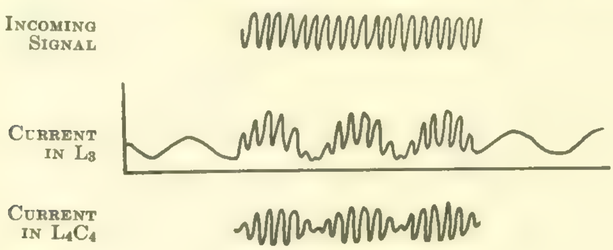


FIGURE 22

response as can be obtained with a single audion working with the beat method of reception. The advantages derived from the heterodyne method of amplification and the dependence of the audio frequency note in the receivers on the wave length are, of course, lacking; but for the reception of waves having a frequency higher than that at which beat reception is practicable, this method is of value.

EFFECTS OF ATMOSPHERIC DISTURBANCES

A very interesting feature of these receiving systems is their behavior under conditions of severe atmospheric disturbances, particularly when used for receiving continuous waves. Their success under such conditions is due to the fact that they com-

bine in addition to their inherent property of responding more readily to a sustained wave than to a strongly damped one, the characteristics of the two most effective static eliminators known; the balanced valve and the heterodyne receiver. The function of the balanced valve is a physiological one, as it simply provides a means to shield the ear from the loud crashes which temporarily impair its sensitiveness for the relatively weak signals. In effect, it puts a limit on the noise which can be produced in the telephone by a stray, regardless of its amplitude. Now the effect of the static on an audion is to build up a negative charge on the grid, reducing the wing current, and the limit of the response which can be produced in the telephones is reached when the wing current is reduced to zero. Under ordinary conditions, this limit is too great to do much good; but when the audion is generating it is possible, by proper adjustment of the amplitude of the local oscillations, to reduce the wing current to a point just above the lower bend in the operating characteristic so that the audion is rendered insensitive to a further increase in the negative charge on the grid. The strays which cause serious interference are of a much greater amplitude than the local frequency, so that no appreciable interaction between the two takes place, and the wing current is invariably decreased. Since the decrease in the wing current is not in proportion to the change in the grid potential, the response in the telephone and the effect on the ear of the operator are correspondingly reduced. Static of smaller amplitude than the local oscillations may interact with them to produce either an increase or a decrease in amplitude of the oscillations in the grid circuit and may therefore cause either a decrease or an increase in the wing current. The wing current can, of course, increase to a relatively large value, but as it is impossible for the wing current to increase faster than the charge in the grid condenser can leak off, the rate of increase is necessarily slow. The response in the telephones is therefore not so disturbing as would be caused by a decrease of similar value where the rate of change of current is usually large.

When the system is operated without an auxiliary leak around the grid condenser, a peculiar paralysis of the audion is frequently caused by heavy static, no sound of any kind being heard in the telephones for a considerable length of time. If the apparatus is not touched, the paralysis may last for many minutes, and then suddenly disappear and the former sensitiveness be restored. The effect is primarily caused by the

charging of the grid condenser to a sufficient potential to cut off entirely the flow of electrons to the wing, thereby decreasing the wing current to zero. Now the way in which the negative charge in the grid condenser leaks off is chiefly by means of the positive ions in the tube, which are drawn into contact with the grid when it becomes negatively charged. These positive ions are the result of ionization by impact, and when the voltage of the wing battery is properly adjusted, they can be produced only in the region between the grid and the wing, since the velocity attained by the electrons between the filament and grid is very low. When the grid is charged to a high negative potential it keeps all the electrons between the grid and filament, thereby barring them from the region between grid and wing. Hence the production of positive ions must cease and the usual means of removing the negative charge from the grid vanishes. The resistance of the leakage path of the grid condenser must then be almost infinite, as is shown by the very long time taken for the charge to leak from a condenser of approximately 0.0001 microfarads capacity. The effect is naturally the more pronounced the higher the vacuum, as the number of positive ions present is correspondingly reduced. A resistance of several hundred thousand ohms placed across the grid condenser gives a leak which is independent of the value of the wing current and which effectually prevents trouble of this kind. With the very high vacua now obtainable by the use of a molecular pump, there are practically no positive ions present so that the auxiliary leak is always necessary. Under these conditions, it not only prevents paralysis by the static but it also removes from the grid condenser the excess of negative electricity which accumulates in it, thereby increasing the sensitiveness of the audion and the sharpness of the signals in the telephones. The very high potentials to which the grid condenser may be charged by the static when it is not provided with an auxiliary leak are surprising. These potentials may be measured in a very simple and accurate way, here described. After a stray has cut off the wing current, if we continuously increase the capacity of the grid condenser the potential across it, and hence the potential of the grid, with respect to the filament, will be decreased inversely as the capacity. A point will finally be reached where the grid potential is sufficiently reduced to allow the wing current to flow. When this occurs it indicates that the potential of the grid condenser is slightly less than that shown by the operating characteristic as necessary to

reduce the wing current to zero. The potential to which the grid condenser was originally charged is equal to th's voltage times the ratio of the capacity of the condenser at which the wing current began to flow to the original capacity. Voltages of over a hundred are not uncommonly reached by the grid; and as one volt represents a very strong signal, the difficulties of the static problem are very forcibly presented.

The fact that static of large amplitude produces almost invariably a decrease in the wing current while a signal (with beat reception) produces alternately an increase and decrease in the wing current is a circumstance of which it should be possible to take advantage. The circuits can be arranged to rectify the wing current in such a way that only the increases in this current are available to produce a response in the telephones, but in carrying this method out, trouble is experienced from a shifting zero. A better way of making use of the difference in response is the following one. Suppose that we arrange two complete receiving systems oscillating in step with each other, but so related to the antenna that the beat currents in the two systems are 180 degrees apart. The result of this will be that at the instant when the incoming signal is producing an increase of current thru the telephones in one receiver, it will be producing a decrease of current thru the telephones of the other receiver; so that the two telephone currents are 180 degrees out of phase. Static of large amplitude does not interact with the local frequencies, and will produce simultaneously in each receiver a decrease in the telephone current. These two currents are therefore in phase with each other. On replacing each telephone by the primary of a transformer, and connecting their secondaries thru a telephone in the proper phase, it is possible to balance out the static and at the same time secure an additive response of the signals from each receiver.

An arrangement of circuits by means of which this method can be carried out is shown in Figure 23. Here two oscillating receiving systems are kept in step by means of the circuits L_1 C_1 C_1' L_1'. L_1 C_1 and L_1' C_1' are identical, and each is tuned separately to the frequency to be received. When both audions are oscillating in step, the flow of current in these circuits as indicated by the vectors of Figure 23 will be alternately up on one side and down on the other. The point between the condenser C_1 and C_1' will be a node; and the antenna may be connected to this point without disturbing the conditions appreciably if a resistance R placed as indicated is included in the

antenna. This resistance need not be large enough to interfere seriously with the signal strength; it need only be large with respect to the resistance of the circuit $L_1\ C_1\ C_1'\ L_1'$, which circuit has a very low resistance.

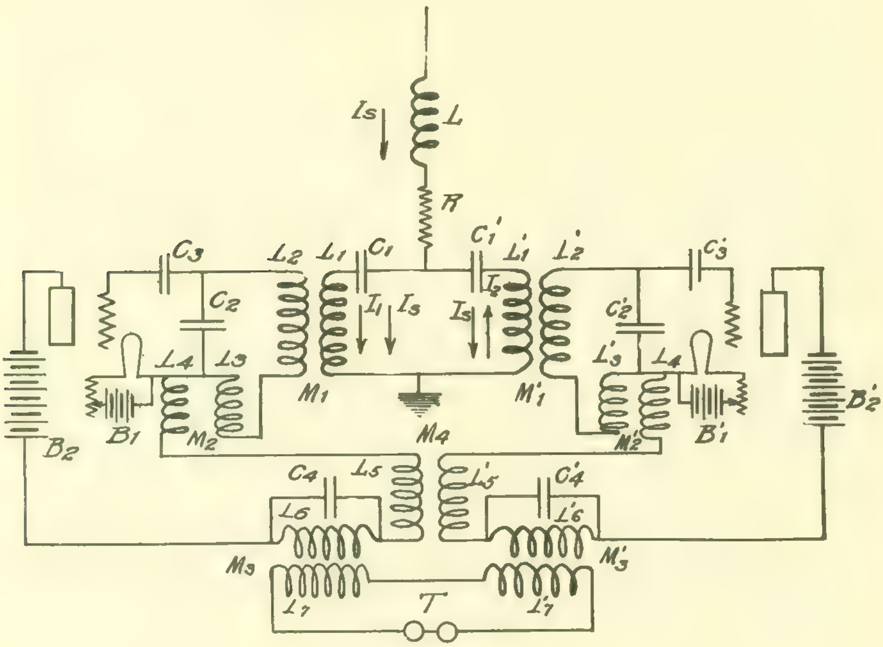


FIGURE 23

Incoming oscillations pass thru the divided circuit as indicated in the diagram, and therefore are in phase with the local oscillations of one receiver and 180 degrees out of phase with the local oscillations of the other. This produces the desired result in the currents thru the transformers of the circuit T which act in the manner already described.

It is found in practice that the oscillations set up in each system by the incoming signals tend to neutralize each other thru the circuit $L_1\ C_1\ C_1'\ L_1'$. This effect is avoided by introducing in the wing circuits a differential coupling arranged to neutralize the coupling between the two grid circuits. It is possible to do this, as it does not affect the coupling of either receiver with the antenna, and does not interfere with the local operation until the effective coupling between the two systems is reduced to a point below which they will no longer remain in step. There are other ways of securing the same result, but the system shown will illustrate the general procedure in carrying out this method of balancing.

The practical results obtainable with these receivers may perhaps be of interest. At the present time, signals from all high power stations from Eilvese (Germany) to Honolulu are heard day and night at Columbia University with a single audion receiver. Cascade systems give correspondingly better results, two stages being sufficient to make the night signals of Honolulu audible thruout the operating room. Interference with the signals from Nauen by the arc station at Newcastle, New Brunswick (Canada), is very easily eliminated by means of an audio frequency tuning circuit; and this is the most severe interference we have yet experienced, the two frequencies sometimes differing by less than 1 per cent. and the arc signals being much the stronger.

These receivers have been developed in the Research Laboratory of Electro-Mechanics, Columbia University; and are mainly the result of a proper understanding and interpretation of the key to the action of the audion; the grid potential-wing current curve. In conclusion, I want to point out that none of the methods of producing amplification or oscillation depend on a critical gas action; they depend solely on the relay action of the tube employed (electron or gas relay) and the proper arrangement of its controlling circuits.

SUMMARY: The action of the audion as a detector and simple amplifier is explained, with the method of verification of the theory by means of oscillograms. To reinforce the oscillations in the grid circuit two methods are employed: first, to couple the grid circuit to the wing circuit and arrange the latter to permit radio frequency currents to pass freely in it; and second, to use a large inductance in the wing circuit, thereby tuning it to the incoming frequency (in conjunction with the capacity between the filament and wing in the audion itself). Both methods may be used together. Various methods of coupling grid and wing circuits are shown. Methods of combined audio and radio frequency amplification are described.

The audion, being a generator of alternating current of any desired frequency, can be used as a beat receiver. A steady audion generator of regular groups of radio frequency oscillations is illustrated. Various methods of audio frequency tuning permitting high selectivity are possible. By the use of two audions in cascade, amplifications as high as 1,000 are attainable. The cascade systems can be arranged so as to operate both audions either synchronously or non-synchronously.

As an alternative to beat reception of sustained wave signals, an arrangement is explained wherein the amplifying ratio of a repeating audion is varied periodically at an audio frequency. Coupled to this system is a simple audion detector. Musical signals of any desired pitch are thus obtained.

It is found that static of large amplitude nearly always decreases the wing current, while a signal (with beat reception) alternately increases and decreases it. A system of circuits is described whereby this fact is taken advantage of in balancing out static while retaining an additive response to signals, thus effecting an elimination of static to a considerable extent.

Finally, instances of long distance stations received and interference overcome in practice are given.

DISCUSSION

Lee de Forest (by letter): Absence from New York and stress of business prevents my giving to Mr. Armstrong's paper the thoro discussion it merits from me.

Briefly, I must state that my investigation of the simple audion detector, the audion amplifier, and the "ultraudion" detector for undamped waves do not bear out completely the results and conclusions announced by that writer.

In the first place, anyone who has had considerable experience with numerous audion bulbs must admit that the behavior of different bulbs varies in many particulars, and to an astonishing degree. The wing potential-wing current curves for different bulbs, or even for the same bulb at different times, under differing conditions (filament temperature, etc.) vary widely.

What may appear to be a fixed law for one bulb may not hold for another.

Mr. Armstrong makes no mention of this well-known fact; nor does he even state that his grid potential-wing current curve may be quite otherwise than he has shown it with different applied "B" battery voltage, or filament temperatures.

He makes no mention of the fact, often demonstrated, that a continuous current indicating instrument, e.g., a micro-ammeter, may show a decrease in deflection, or practically no change in deflection either way when fairly strong radio frequency (or audio frequency) impulses are delivered to the grid even when the telephone receiver in the wing circuit gives strong response.

I have frequently proven that a *positive* charge applied to the grid, may decrease, rather than increase the "wing current." If I may say so, he treats the entire subject in much too cursory and cavalier a manner, even as he appears to be quite oblivious of the work of any other investigator or discoverer.

As I stated in an article in the "*Electrical World*," February 20th, the *oscillating* quality of the audion was discovered by me several years ago.

I found that the complicated circuits Mr. Armstrong illustrates were quite unnecessary for producing the effects mentioned. In fact, the combination of oscillating and amplifying functions in the same bulb are obtained almost, if not quite, as efficiently, and far more simply by much simpler circuits.

The second method he shows for a combination tuning to radio and audio frequencies is ingenious and highly creditable. Un-

fortunately, as he truly points out, there is to-day no continuous wave generator of sufficiently constant frequency to permit full advantage being taken of this elegant method.

Edwin H. Armstrong: The condition in which a positive potential applied to the grid produces a decrease in the wing current is a remarkable one, in that it has been the cause of that mysterious atmosphere with which the audion has long been surrounded. The effect occurs under certain conditions which are very easily explained. Suppose there is an appreciable amount of gas in the tube and the difference of potential between the wing and filament is adjusted so that a considerable number of positive ions are produced. In such a state it frequently happens that the number of positive ions coming in contact with the grid is in excess of the number of negative ions. As a consequence of this the grid assumes a positive charge with respect to the filament. Suppose the potential to which the grid becomes charged is three volts positive with respect to the negative terminal of the filament. Under these conditions a battery of say one or two volts connected as shown in Figure 1 with its

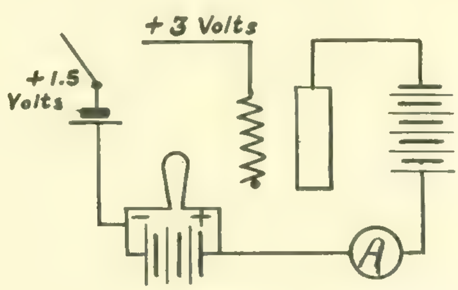


FIGURE 1

positive terminal connected to the grid will really change the potential of the grid in the negative sense. The natural result is a decrease in the wing current. The converse of this effect: the condition in which a negative potential applied to the grid produces an increase in the wing current, is invariably met with in high vacuum audions where the potential assumed by the grid is invariably negative. Both cases, however, can be explained on the same grounds. Figure 2 shows the potential assumed by the grid when a large number of positive ions are present.

Edwin H. Armstrong (by letter): In replying to Dr. de Forest's communication, I want to point out that the paper was

intended to deal with the application of circuits of a new type to the actuation of the audion. The fundamental operating features of the audion itself were outlined purely as a basis on which to explain the action of the circuits. A detailed explanation of the various phenomena involved in the audion as a detector and as a relay, radically different from that previously advanced by Dr. de Forest, was published by me some time ago in the "*Electrical*

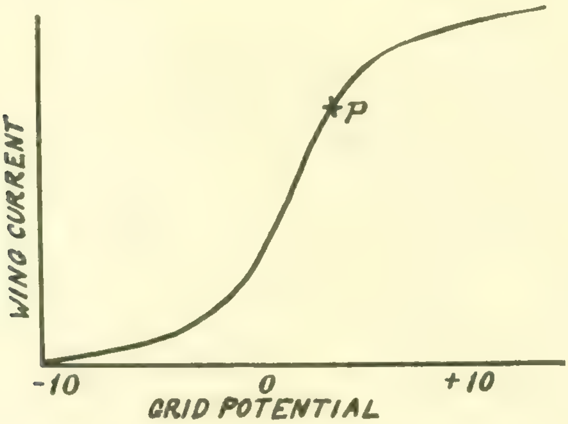


FIGURE 2

World," December 12th, 1914, and the columns of that paper, are, no doubt, still open to discussion of these elementary matters.

Dr. de Forest speaks of the great differences existing between the wing potential-wing current curves. It will be readily understood by those familiar with the laws of the conduction of electricity thru gases that such is bound to be the case where any considerable amount of gas is present in the bulb. The potential at which progressive ionization of the gas begins, is dependent, among other things, on the pressure; and hence the upper parts of the wing potential-wing current curves vary, but the lower parts, *the only place where the electron relay can be operated*, are invariably of the same general shape. With the modern methods now available, for producing very high vacua, it is a simple matter to construct audions whose characteristics are for all practical purposes identical. With these high vacuum bulbs, the astonishing differences of which Dr. de Forest speaks disappear to an astonishing extent.

The great differences which sometimes exist between the grid potential-wing current curves of different audions or for the same audion under different conditions of wing potential or

filament temperature are again due to the residual gas, and are eliminated as before by the use of very high vacua. It will be evident, of course, that for each value of wing potential and filament temperature there will be a different grid potential-wing current curve; but for high vacuum bulbs these curves lie one above the other in an orderly manner and, barring minor differences, are of the same general shape.

For an explanation of the fact that a continuous current instrument in the wing circuit shows no change in deflection when an alternating e. m. f. of *audio* frequency is impressed on the grid even when a telephone in circuit with the meter gives a strong response, I want to call attention to Figures 2 and 5, of the original paper, together with a suggestion that a telephone perhaps is apt to respond somewhat more strongly to an alternating current than does a continuous current instrument! An explanation of the decrease of wing current which may occur will be found in the publication in the "*Electrical World*," December 12th, 1914, with an accompanying oscillogram which shows the asymmetric effect in question. The circumstance stated by Dr. de Forest in which a *radio* frequency e. m. f. impressed on the grid produces a response in a telephone but not in a continuous current instrument is an impossible one. If the telephone responded, and there were no changes in the reading of the instrument, it would be an indication of an alternate and equal increase and decrease of the wing current at an audio frequency rate. This is an effect which *radio* frequency oscillations applied to the grid cannot produce. When a condenser is used in connection with the grid, radio frequency oscillations invariably produce a net decrease in the wing current and hence a decrease in the telephone current. Where use is made of the asymmetric relaying, which is possible because of the bends in the operating characteristic, either a net increase or net decrease may be produced in the wing current by radio frequencies applied to the grid, depending at which bend the audion is worked, but an increase and decrease can never be produced at the same time.

Dr. de Forest attempts to throw doubt on the validity of the operating characteristic, and hence on all explanations depending thereon, by stating that he has frequently proven that a positive charge applied to the grid may decrease rather than increase the wing current, a contention originally advanced by him in explanation of the relay and detecting action of the audion. In the discussion, I have pointed out the fallacy in this

view and explained the seeming paradox which is found in low vacuum bulbs on the working part of the grid potential-wing current curve. There is another effect which may lead to incorrect conclusions concerning the action of the electron relay, which is due to effects found above the working part of the curve. As the potential of the grid is increased, it is possible that the wing current may reach a maximum and then fall off. This is due to the fact that a conduction current flows to the grid when it is positive with respect to the filament, and that under certain conditions, this current is subtracted from the wing current. The maximum current which can flow from filament to wing is limited to the number of electrons emitted by the filament, and if the condition of maximum current flow in the wing circuit is established before the grid potential becomes highly positive, then a further increase in the grid potential will increase the number of electrons absorbed by the grid and the result is a decrease in the wing current. The impossibility of working an electron relay on this part of the curve will be evident from the accompanying diagrams (Figure 3) which show how the effective resistance of the input side of the audion increases as

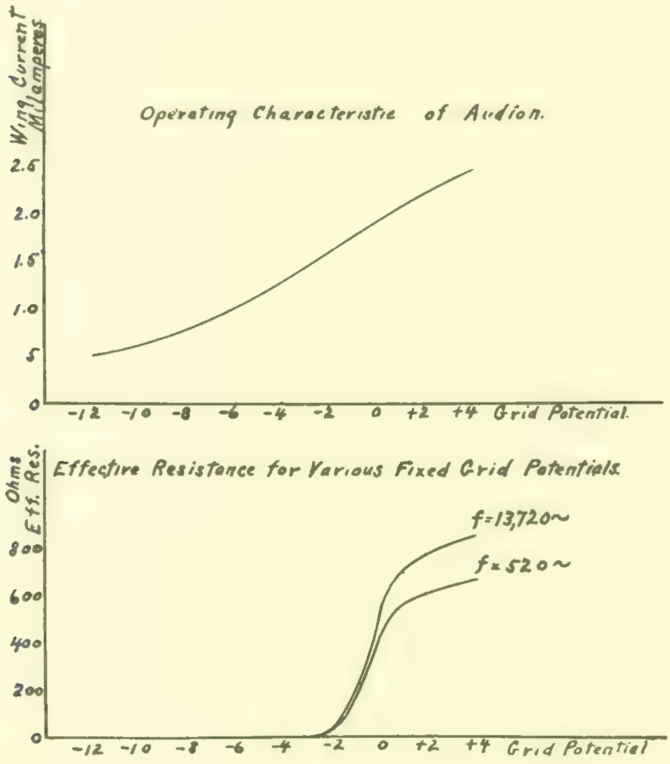


FIGURE 3

the potential of the grid is varied. Only when the grid is negative with respect to the filament can the full amplifying power of the audion be realized, as the input side consumes no energy. Herein lies the explanation of the great differences which exist in the amplifying powers of different bulbs when used in the customary fashion. It is usual to operate the audio frequency amplifier with the grid insulated from the filament for conduction currents so that the potential of the grid is determined solely by the characteristics of the audion. If it should chance to be sufficiently negative, the input side consumes no energy and the result is a good one; if it should be positive, then the input side consumes energy and the amplification is seriously impaired, the degree depending on the value of the positive charge. All this is clearly supported by the fact that when the potential of the grid of a good bulb is arbitrarily made positive, the amplification falls off. The curves shown in Figure 3 are additional confirmation, and in this connection it is interesting to note the agreement between the radio and audio frequency curves.

The statement by Dr. de Forest that he originally discovered the oscillating phenomenon and applied it to producing the effects described several years ago cannot be here discussed, because his priority in this matter will be contested shortly in another way.

Lee de Forest (by letter): While I cannot accept Mr. Armstrong's explanations of my observations as to the action of a positively charged grid on the wing current, they have at least more to recommend them than has his previous flat contradiction that such an effect as I have described existed at all.

What Mr. Armstrong states are "elementary matters" have not appeared so to associates and collaborators of Drs. Rutherford and Soddy with whom I have discussed them. These discussions, however, were prior to the appearance of Mr. Armstrong's paper.

In spite of Mr. Armstrong's explanations, we are left quite in the dark as to how high these consistent vacua are, and just what operating voltages he refers to. More quantitative explicitness and citations of the exact performances of scores of bulb would be more convincing than are the theories proposed as a basis for description of sundry complicated circuits.

If he is dealing with a type of tube which is quite distinct from the audion (on account of the degree of vacuum, the applied potentials, etc.), this should have been explicitly stated

at the outset. This is my chief complaint. No essential data are given, but only general laws with attempted axioms. I assumed that we were dealing with phenomena in the audion as popularly known, operating on from 20 to 50 volts. With such, at least, there still remain some unexplained problems.

If he be unable to explain my observation that, using audio frequencies, certain bulbs show a decrease, others no perceptible change in deflection of a direct current micro-ammeter while a telephone receiver gives responses many times audibility—this fact should be frankly stated. I should also like to have his explanation as to why certain audions are distinctly more sensitive to low than to high spark frequencies while others show the exact reverse. Tho I have theories on this point, I have not yet proven them.

In connection with Mr. Armstrong's insistence on the value of his oscillograms which were taken at audio frequencies because audio and radio frequency phenomena are identical in nature, I should like to call attention to his statement that "This is an effect which radio (as distinguished from audio) frequency oscillations applied to the grid cannot produce."

Is it not perhaps possible that where successive strongly damped wave trains, of radio frequencies, have alternately positive and negative initial wave fronts, an alternating increase and decrease of wing current may occur which would, while giving loud signals in the telephone receiver, produce practically no change in deflection in a direct current micro-ammeter in series therewith?

As to Mr. Armstrong's closing remark, I had not before realized that he actually claimed broadly the discovery of the oscillating property of the audion. I think it can and will be established that this was discovered some time before his first work in this field. If any are still of the opinion that the oscillating quality of the audion awaited the discovery of the complicated circuits he describes, I would refer them to the article on "The Double Audion Type of Receiver," by Professor A. H. Taylor, in the "*Electrical World*" of March 13th, 1915.

Edwin H. Armstrong (by letter): Replying to Dr. de Forest's latest communication in regard to the effect of a charged grid on the wing current, I cannot but assume, from his failure to produce evidence to the contrary, that his observations may be explained by the residual positive charge on the grid. This applies to that type of tube in which so many "unexplained"

phenomena are observed; "the audion, as popularly known, operating on from 20 to 50 volts."

Dr. de Forest's misapprehension as to the type of tube referred to in the paper rests entirely with himself. It was definitely stated in the article in the "*Electrical World*," and on the occasion of the presentation of this paper before the Institute of Radio Engineers that the vacuum of the bulbs was such that only thermionic currents existed. The methods used to obtain these vacua were those recently described by Dr. Irving Langmuir in a paper presented before the American Physical Society, and also in another paper presented before the Institute of Radio Engineers (See this issue of the PROCEEDINGS, together with the discussion on Dr. Langmuir's paper).

In explanation of Dr. de Forest's observation that audio frequencies applied to the grid may produce either a decrease or no change in the reading of a *direct* current micro-ammeter, while a telephone responds strongly, I have pointed out the oscillograms which fully explain both cases. It seems necessary to add that a *direct* current instrument of the type mentioned measures *average* values!

The question of the relative sensitiveness of an audion as a detector to high and low spark frequencies is entirely irrelevant to the present discussion. It has, however, some points which are of interest. The effect occurs only when the valve action of the audion is used to rectify the oscillations and a condenser is necessarily used in series with the grid. When there is a scarcity of positive ions, the rate of leak of the charge accumulated in the grid condenser from one group of oscillations may be so slow that the condenser fails to clear itself before the arrival of another group of oscillations. Under these conditions, a residual negative charge is continuously maintained in the grid condenser during the periods of signaling, and this charge interferes with the rectifying action between grid and filament. Obviously, this effect will be more pronounced at the higher spark frequencies, and the sensitiveness of the audion will be less impaired on the low spark frequencies. The phenomenon is an interesting one, but on the whole it is quite simple and elementary in character.

Dr. de Forest attempts to explain the circumstance which I have shown is impossible—the circumstance in which radio frequencies applied to the grid produce response in a telephone in the wing circuit but no change in the deflection of a continuous current instrument in series with the telephone. The explana-

tion advanced is impossible. The effect described could be produced only by wave trains that were practically aperiodic. Needless to say, nothing remotely approaching this is in use in radio telegraphy at the present time.

In conclusion, I wish to point out that this discussion was originally begun by Dr. de Forest in an attempt to invalidate the explanations advanced to account for the various detecting, repeating, and oscillating phenomena. It is my opinion that the explanations given stand as correct.

Robert H. Marriott: It has been frequently charged that there has been a lack of research in radio engineering carried out in physical research laboratories. Mr. Armstrong deserves much praise in carrying out his highly interesting investigation, and it is to be hoped that further valuable results will be obtained under similar auspices.

(**This discussion is herewith closed.**—EDITOR.)

THE METHODS EMPLOYED FOR THE WIRELESS COMMUNICATION OF SPEECH

[Parts] I-V

Philip R. Coursey

The Methods Employed for the Wireless Communication of Speech

By PHILIP R. COURSEY, B.Sc.

(Read before the Students' Section of the Institute of Electrical Engineers, on February 2nd, 1916.)

THE communication of speech and other sounds from place to place without the intervention of any wire connection is no novelty, and the method of the ancients is still in use to-day. This transmission of sound by air waves is seldom, however, looked upon as being included under the generally accepted meanings of the term "wireless telephony"; and there is little need, therefore, to devote more consideration to it.

Wireless telephony seems still to be periodically "invented" in the columns of the daily Press, although its first inception dates back to the beginnings of the much better known wireless telegraphy.

The various methods that have been suggested from time to time for effecting telephonic communication between two or more places without the aid of connecting wires may be broadly classified as follows:

(*a*) Conduction and induction methods, employing the conductive connection of the earth or sea, or magnetic induction between circuits;

(*b*) Photophone and thermophone methods employing light or heat waves as the transmitting medium.

(*c*) Wave methods employing æther waves of the same kind as used in ordinary wireless telegraphy.

THE CONDUCTION AND INDUCTION SYSTEMS.

The conduction and induction methods of wireless telephony were obvious extensions of the use of this type of apparatus in the early days of wireless telegraphy: since speech could be effected between the two stations merely by replacing the transmitting key and source of interrupted currents, by a microphone with a suitable battery or generator. It may be convenient to briefly call to mind the arrangements before passing on to a consideration of the more important methods and apparatus.

These methods have been applied, amongst other purposes, for telephoning between the various levels in mines, and it is interesting to note that comparatively recently these systems have been "revived" and successfully utilised for this purpose, the apparatus required being extremely portable and suited to the conditions of use.

PHOTOPHONE AND THERMOPHONE SYSTEMS.

The majority of photophone systems depend on the fact that when light falls on selenium its resistance decreases, in amount depending within limits on the intensity of the illumination. To obtain the best effects it is essential that a considerable surface should be exposed to the action of the light, while, in addition, the cross sectional area through which the current flows should be as large as possible and the length small, on

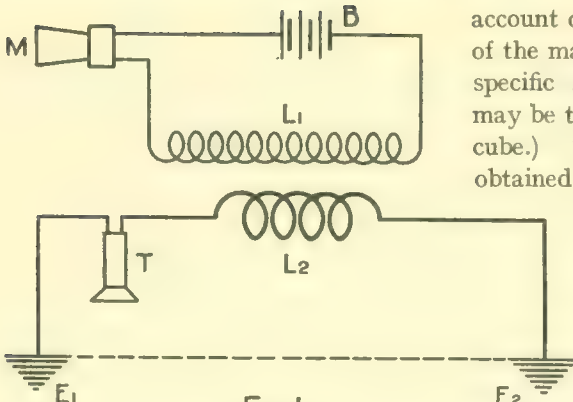


Fig. 1.

ARRANGEMENT FOR CONDUCTION METHOD, USING MICROPHONE TRANSMITTER.

account of the very high specific resistance of the material. (An average value of the specific resistance for crystalline selenium may be taken as about 60,000 ohms per cur. cube.) These results are most conveniently obtained by spreading a thin film of selenium over a number of parallel wires, which form the electrodes of the completed "cell."

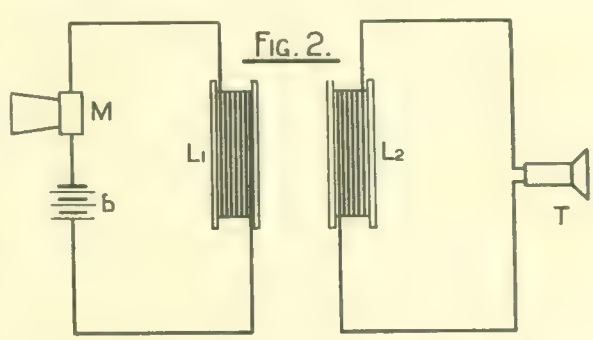
One proposed form, due to E. Ruhmer (who carried out a considerable amount of experimental work in this branch of the subject), consists of a spiral of two wires wound round a flat piece of porcelain or mica with a small space between them. The selenium is then spread over them in a fused condition, and annealed by heating the completed cell in order to convert the selenium into the grey crystalline variety, which is more sensitive to light. Another form consists of a pair of wires wound round a cylinder of porcelain, or other suitable material, the selenium being spread over them as in the other type, and subsequently annealed by heating. The wire employed is usually platinum. See Fig. 3.

As the change of resistance of the selenium depends on the intensity of the illumination, it is evident that if we can cause the intensity of a beam of light to vary with the modulations of the speech waves, we shall, by connecting a telephone receiver in circuit with the selenium cell, be able to transmit articulate speech along the beam of light.

This, in brief, is the essence of all arrangements of photophones, the differences being mainly in the various light sources employed and in the means of modulating the intensity of the light. Time will not permit, however, of more than a brief mention of one or two of the most important and successful methods.

By employing parabolic mirrors at both the transmitter and receiver, so as to obtain a parallel beam of rays and to utilise as much as possible of the beam at the receiver, the speaking range of this type of apparatus may be increased, but, in any case, is limited to the visibility of the source of light employed.

One of the earliest light sources used for this purpose was a gas flame, from its ease of control by the voice, the arrangement being that of the well-known manometric flame. Its range is, however, of necessity extremely limited, being available for little more than demonstration purposes on account of the feebleness of the light source.



ARRANGEMENT FOR INDUCTION METHOD.

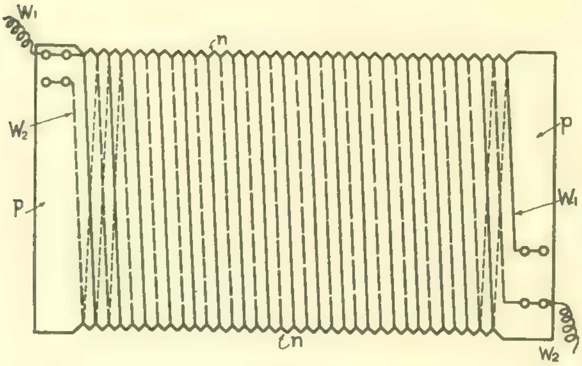


FIG. 3.

The greatest utility of the photophone is obtained when a powerful arc searchlight is employed at the transmitter, the light intensity being modulated by means of an ordinary microphone transmitter acting on the arc current.

In this manner successful working has been obtained up to distances of 20 miles or more. See Fig 4.

A point in connection with the operation of these methods is that it is possible to employ light screens so as to cut off *all* the visible light (or any desired portion of it), and to use, say, merely the invisible infra-red rays. Such an arrangement renders the working very secret, as no outward indications are given at all of the messages passing. A further step from the use of infra-red rays is to employ heat waves only, and a delicate thermopile or similar heat-detecting arrangement (with a telephone) at the receiver. The speaking range of these "thermophones," as they are called, is, however, not nearly so great as that of the photophones employing light waves, while they are not so satisfactory in operation in other ways.

Desiderata for Successful Wireless Telephony by Æther Waves.

We are now led to a consideration of the main branch of our subject this evening—viz., the practical methods of wireless telephony involving the use of long æther waves of the same kind as those commonly utilised in ordinary wireless telegraphy—that is, waves of length within what is customarily called the "wireless range" of, say, 200 or 300 metres up to about 10,000 metres wave-length. (Frequencies between 30,000 and about 1 or 1½ million per second.)

A little investigation, however, soon shows that the problems presented in this case are rather different from those of ordinary wireless telegraphy. An outline of the requirements may be given as follows:

At the transmitter must be set up a stream of æther waves suitable for affecting the distant receiver (much as in wireless telegraphy by the same means). This stream of waves will produce a certain continuous effect at the receiver. It is necessary, therefore, to modulate this stream of waves, according to the modulations of the speech or sound waves, just as the light of the arc is modulated in the photophone transmitter to produce at the

FIG. 4.

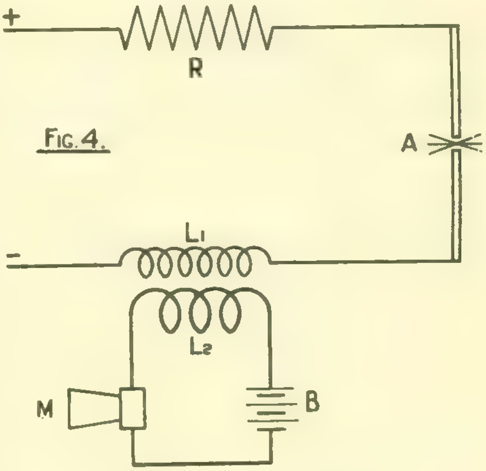


DIAGRAM OF "TALKING ARC" CONNECTIONS.

receiver effects which are a more or less faithful copy of the speech or sound waves impinging on the transmitter, and which may, therefore, be made audible by the use of the customary telephone receivers. (Fig. 5)

The practical realisation of the above is not, however, as simple as it appears at first sight. To begin with, we have to produce a perfectly steady stream of waves at the transmitter, which shall be capable of affecting the receiver, but which must *not produce any sounds in the receiving telephones* under normal conditions—*i.e.*, when no speech is being transmitted ; this means either that the waves emitted must be perfectly continuous (like an ordinary alternating current), the frequency, of course, being above the acoustic limit of about 30,000 per second, or, that if the wave emission is discontinuous (as in ordinary spark wireless telegraphy), the successive groups of sparks must follow one another so quickly that the "sound" they give rise to in the receiving telephones is above the acoustic limit, and so inaudible.

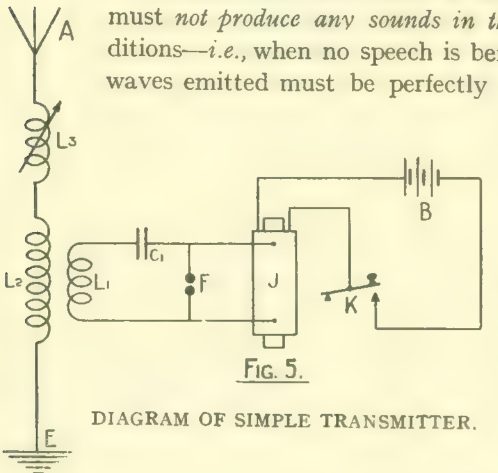


FIG. 5.

DIAGRAM OF SIMPLE TRANSMITTER.

Hence we see at once that the transmitting apparatus for æther wave wireless telephony may be roughly divided into two main classes :

1. Those producing continuous waves ; and

2. Those producing discontinuous groups of waves of very high group frequency.

The practical realisation of either of these methods involves considerable departure from the usual apparatus of ordinary musical note-spark telegraphy in the majority of cases, as, for example, considerable difficulties are at once introduced if we attempt to raise the spark or group frequency much above the values that are customarily employed —*i.e.*, up to, say, 1,000 sparks per second. More especially is this the case if we attempt to employ some form of rotary spark gap—such as the Marconi disc discharger—to produce these very high spark frequencies by direct means, the difficulties being mainly in the mechanical construction for the very high speeds of rotation that would be necessary. A means of solving the problem has recently, however, been discovered, which promises successful operation. This will be referred to later in the paper.

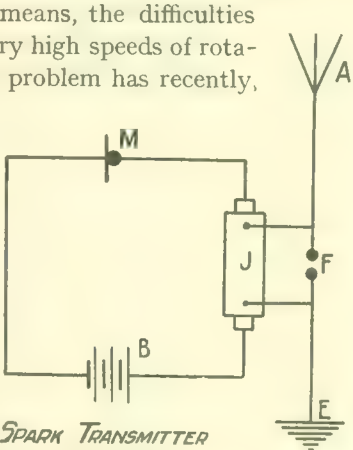
Hence other methods of generating the required oscillations must generally be resorted to. They may be classified as follows :

For generating continuous waves we have—

1. Arc apparatus ;

2. Alternator and frequency raising apparatus ; and

3. "Vacuum methods," involving the employment of and electrical discharge through a rarefied gas or vacuum.



EARLY SPARK TRANSMITTER WITH MICROPHONE.

FIG. 6.

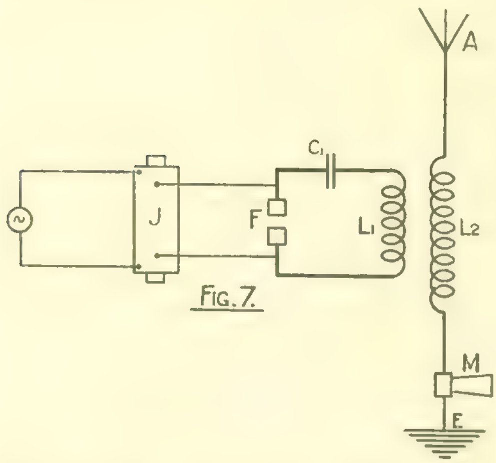


FIG. 7.

For generating discontinuous waves of high group frequency we have—

4. Short spark methods, generally employing some form of quenched spark gap.

The above classification, however, must not be looked upon as an absolutely rigid one, as we find that several of the available pieces of apparatus do not strictly belong to either class. For instance, it is usually understood that the expression " discontinuous groups of waves " implies a succession of wave trains, each of which dies out completely before the succeeding one commences ; whereas some apparatus usually referred to this class really produces a rapid series of trains of oscillations which run into one another, giving rise to waves of fluctuating amplitude which do not actually die out at any time.

On the other hand, we shall find that some of the short-spark methods (usually classed as producing discontinuous waves), really generate oscillations which, to all intents and purposes, may be said to be undamped. The classification must therefore only be looked upon as one to assist the treatment of the subject from the descriptive point of view.

Almost as soon as Marconi first outlined his schemes for wireless telegraphy several proposals were put forward for enabling telephonic communication to be carried out by the same means.* The majority of them merely consisted in taking the ordinary wireless telegraphy transmitter in use about that time and adding to it some means of modifying the emission of the waves, according to the sounds to be transmitted. The following diagram shows one proposal in this connection, and may serve as an illustration of the methods adopted. It consists of a simple wireless telegraph transmitter, with the addition of a microphone connected in the supply circuit to the induction coil, instead of the usual interrupter, the idea being that the changes of microphone resistance produced by the sounds to be transmitted would cause sparks to pass across the gap of the required strength and frequency to transmit the sound waves. (See Fig. 6.) As a receiver, any one of the microphonic contact or auto-decohering detectors in common use about that time (*i.e.*, about 1900 to 1905) was employed in conjunction with a telephone receiver. A certain measure of success was obtained in that rhythmic sounds or notes could be transmitted, but articulate speech was practically out of the question since the wave form of speech is far too irregular for the combination of induction coil and open spark gap to follow with any measure of success.

Other proposals involved the addition of a microphone to a wireless telegraph transmitter while retaining the induction coil with its interrupter. (Fig. 7.)

The obvious disadvantage of this arrangement is that the microphone can only operate during a train of oscillations, while in the relatively long interval between the successive wave trains it can produce no effect whatever. Hence, any speech or other

* See, for example, U.S.A. Patent, 14540, 1906 ; French Patent, 365160, 1906 ; British Patent, 28955, 1896 ; German Patent, 138226, 1901. *Electrotechnische Zeitschrift*, 25, p. 1085 ; and 26, p. 65, 1905.

sounds received will be extremely imperfect (it has been found that some musical notes can be transmitted in this way, but not speech), while in addition there will be the continuous noise of the spark, corresponding to the frequency of the induction coil interrupter, which will be received the whole time.

In short, it may be seen at once that such an arrangement does not comply with the requirements laid down above for the successful working of wireless telephony by æther waves.

In passing it may be mentioned here that the connection of the transmitting microphone in the aerial circuit of the transmitter, as here shown, is now most commonly employed with success with the modern transmitters—the fault in this case lies not in the connections, but in the oscillation generator. In endeavouring to overcome the above difficulties of low spark frequencies, attempts were made to replace the original induction coils by alternating current transformers, with the spark gaps so arranged that a considerable number of discharges took place in each half cycle of the voltage wave, which should preferably approach a rectangular shape rather than the usual sine curve.

The addition of two or more spark gaps, and oscillation circuits (all influencing the same aerial), and fed from a three phase, or polyphase, alternating current enables the spaces which occur near the zero of each half wave of the A.C. voltage to be filled up, and the effective sparking rate rendered nearly uniform.

It is interesting to note that these methods have comparatively recently been revived and applied to more modern apparatus than that for which they were originally intended. By employing a suitable design of spark gap it has been found possible to obtain sufficiently rapid discharges to enable intelligible speech to be transmitted over short distances.

The employment of three phase alternating currents, with three spark-gaps and oscillation circuits, has also been more usefully applied in conjunction with modern alternators designed to deliver 5,000 to 10,000 cycles per second, and using quenched spark-gaps properly tuned to give uniform sparking once on each half wave of the alternating current. It is possible to obtain in this manner a very uniform regular group frequency, which may be above the acoustic limit, and therefore suitable for the transmission of speech.* *(To be Continued.)*

* See Eisenstein, U.S. Patent, 99183, 1911; also *Proc. Inst. Radio Engineers*, 2 pp., 217 and 235; *Sci. Abs.*, 18 B, No. 728, 1915. See also E. G. Gage, *The Electrician*, 73, p. 731, 1914.

The Methods Employed for the Wireless Communication of Speech (ii)

By PHILIP R. COURSEY, B.Sc.

(Read before the Students' Section of the Institution of Electrical Engineers, on February 2nd, 1916.)

The Arc Methods of Generating Oscillations.

If we take an ordinary continuous current arc and, while maintaining the arc length constant, we vary the current passing through it, and at the same time measure the P.D. between its terminals, we obtain what is called the characteristic of the arc. In the case of all ordinary arc discharges, this characteristic is what is called a " falling " or " negative " one, that is to say, when the current is increased the voltage falls, and *vice versa.*

Hence, if we connect across such an arc an oscillation circuit containing a condenser, there will be a sudden rush of current into the condenser tending to charge it : this current rush will momentarily cause a decrease in the arc current with, as a result, a corresponding rise of the P.D. across the arc terminals. This voltage rise tends to further charge the condenser to a voltage *above* the normal running voltage of the arc. As soon, therefore, as the charging current of the condenser begins to fall off the arc current will rise again to its normal value, accompanied by a fall of P.D. across its terminals.

We have now the condenser charged to a higher voltage than that across the arc, and as a consequence it immediately begins to discharge back through the arc.

This discharge current is in the same direction through the arc as the supply current, and hence causes a fall in the arc P.D. by reason of the increased current. This further facilitates the condenser discharge. As the condenser completes its discharge, the arc current falls and the P.D. rises again to their normal values, when the cycle is repeated over again and continues indefinitely as long as the supply is maintained and the arc retained of a constant length.

Hence the condenser will be continuously charged and discharged at regular intervals, depending on the inductance in the circuit, the capacity of the condenser, and the length and other conditions of the arc—in other words, continuous oscillations will be set up in the circuit by virtue of this action of the arc.

Looking at the production of oscillations in this way, we can at once see that the strength of the oscillations set up in the shunt oscillation circuit depends on the " steepness " of the arc characteristic, since, if we have an arc with a steeper characteristic curve, a given change in the current through the arc will give rise to a greater variation of the voltage at the arc terminals than it would under similar conditions with a " flatter " characteristic, or, in other words, greater charges will be im-

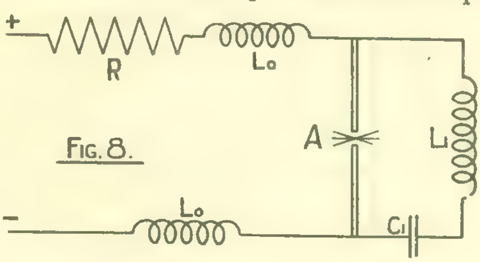


Fig. 8.

parted to the condenser in each cycle, with a correspondingly greater amplitude of the discharge current—*i.e.*, more energy will be imparted to the oscillation circuit, and the oscillations will be consequently vigorous. Hence, it is easier to make an arc with a steep characteristic oscillate than it is one with a flatter curve; and as it is always more difficult to make an arc generate high frequency oscillations than it is low frequency ones, it follows that we require an arc which has a very steep characteristic in order to produce oscillations of wireless frequencies with any degree of readiness. By inspection of the characteristics, we see that they become much steeper for small arc currents, while at the same time for a given current a longer arc at higher voltage has a steeper characteristic, and hence in general low current arcs oscillate better than heavy current arcs—in fact, it is found, as soon as one begins to experiment with such arcs, that there are certain fairly well-defined current limits and arc lengths within which it is necessary to keep if oscillations are to be set up at all. The exact values of the current limits depend entirely on the type of arc and carbons, its length and conditions of use, and also on the values of the capacity and inductance in the shunt circuit.

As a rough guide for experimental purposes it will generally be found necessary to limit the supply current value to not more than about 2 or 3 amperes when employing arcs in air between ordinary solid arc lamp carbons, if it is desired to generate oscillations approaching wireless frequencies. With lower frequencies the supply currents may be increased. The arc length must, moreover, be kept very short. On the other hand, if very high frequencies are desired for experimental purposes, it will be generally found advantageous to employ special carbons for the arcs. Some grades of graphite rods are very suitable for this purpose, while the employment of compressed air or other gases round the arc often leads to considerable advantages from the point of view of the steadiness of the oscillations that are produced, as well as their intensity. The ratio of the capacity to the inductance in the oscillation circuit is also very important; a rough guide to begin with may be taken as ratio of inductance to capacity=about 100, when both are measured in absolute units (centimetres). This figure is, however, liable to very considerable variations to obtain the best effects, depending on the arc employed, on the supply voltage, and current, and more especially on the gas surrounding the are. The use of a suitable choking inductance in the supply circuit to the arc is also important to secure more vigorous oscillations by confining them to the oscillation circuit and preventing them going back on to the supply mains. From the above it is evident that, as the allowable current through the arc is limited in order to secure efficient generation of the oscillations, it is essential to employ high voltages if any considerable oscillatory energy is required. These results are best obtained by connecting a number of arcs in series, and running them off a high voltage supply circuit, with a common oscillation circuit connected across all the arcs. This method has been employed from time to time by various manufacturers in attempts to produce a commercial form of apparatus suitable for the generation of powerful oscillations.

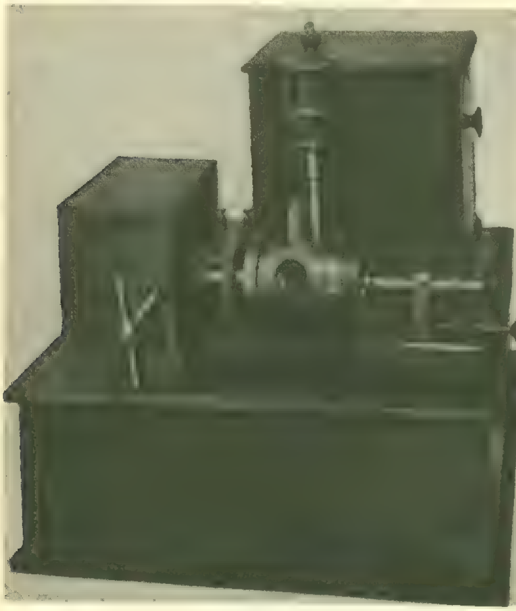
The Poulsen Arc.

About 1902 V. Poulsen discovered that if an arc were set up in an atmosphere of hydrogen or coal gas instead of air its characteristic was much steeper than that of the same arc burning in air, hence he employed such an arc in an atmosphere of hydrogen as a generator of continuous oscillations of wireless frequencies. It was also found

that the use of a water-cooled copper anode with a carbon cathode for the arc when used in the hydrogen or coal-gas atmosphere, referred to above, resulted in the production of steadier and stronger oscillations ; while the employment of a transverse magnetic field across the arc was also claimed in his patents as additional means of ensuring steady and vigorous oscillations.* These features form the essentials of all the Poulsen arc apparatus, although, as is only natural, a number of improvements and alterations have been carried out from time to time in the commercial development of the apparatus.

The use of the electromagnets in the Poulsen apparatus was with the object of maintaining the arc in a definite position on the electrodes, and of a definite shape and length, and thus served to render the arc more regular and the oscillations more stable. It is possible also to so arrange a radial magnetic field in the neighbourhood of the arc that the arc keeps moving round the edge of the electrodes, thus bringing fresh electrode surface into play, and maintaining the arc at a more constant length by promoting a more regular wear of the electrodes. By this means it is possible to dispense with the necessity of rotating one of the electrodes (generally the carbon) that is otherwise necessary to ensure even wear of the electrode and regularity of the arc.

It has also been suggested, however, that the use of the powerful magnetic fields customary in the Poulsen apparatus has a greater utility than that of causing a mere steadying of the arc ; and that the strong field really causes vibrations or oscillations to be set up in the arc, after the manner of arc interrupters, the arc being actually blown out by the magnetic field in some cases, and then automatically restruck again by reason of the applied voltage being sufficient to jump the small ionised space between the electrodes. Some such action as this may possibly take place in the Poulsen apparatus, as with suitable design it is found possible to increase the allowable current passing through one arc from a few amperes, which is all that is possible when operating in air with no magnetic field, to 25 or more amperes when used in the commercial Poulsen apparatus. This leads to a considerably increased output from the arcs.† The conditions which determine the production of oscillations of maximum intensity from arcs, from the point of view of the influence of the supply voltage, current, shunt capacity, frequency of oscillations, etc., have been studied by a number of



AN ARC GENERATOR USED FOR WIRELESS TELEPHONE TRANSMISSION.

* See V. Poulsen, British Patent No. 15599, 1903.

† See, for example, De le Rive, *Pogg. Ann.*, 76, p. 281 (1849) ; Ruhmer, *Electrotechnische Zeitschrift*, 26, p. 382 ; Kosler, *Electrotechnische Zeitschrift*, 28, p. 142 (1907) ; Hahnemann, *Electrotechnische Zeitschrift*, 28, p. 353.

different experimenters. Reference may here be made, for example, to a paper by F. Mercer recently read before the Physical Society of London * on this subject. His conclusions may be summarised as follows :

"1. There is a definite value of inductance for any given capacity which gives a "maximum current in the shunt circuit.

"2. The effect of increasing the gas pressure becomes more marked as the electric "pressure is increased, but as the gas pressure rises the steadiness of the arc diminishes. "The effect is somewhat similar to that obtained by increasing the arc length.

"3. Any effort made to increase the output by the use of a magnetic field, or by "altering the arc length, or the resistance in series with the arc, is detrimental to the "steadiness of operation."

These conclusions were of necessity obtained from the consideration of a limited number of experiments made on one type of arc (the copper-carbon arc in air), and therefore cannot be applied to any and every type of arc oscillation generator without modification.

Dr. Fleming's "Oil-Arc."

A recent development of the Poulsen arc apparatus enclosed in an atmosphere of hydrogen is one that has been carried out at University College, London, under Dr. Fleming, with the idea of dispensing with the cumbersome electromagnets required to produce the magnetic fields used in the Poulsen and other similar apparatus, and also of the necessity of providing a continual supply of hydrogen or coal gas.

Moretti has recommended the employment of an arc in an atmosphere of water vapour,† while in many other forms alcohol or methylated spirit vapour has been used to provide a hydrocarbon atmosphere to obtain an arc with a steep characteristic suitable for generating powerful oscillations.

In the oil-arc a number of arcs between carbon and copper electrodes are struck just over the surface of a heavy oil. The heat generated by the arcs causes vaporisation of the oil, and consequently an atmosphere of hydrocarbon vapour is created round the arcs.

No magnetic field is employed, and the oil generally provides sufficient cooling without having to resort to water cooling, but a water circulation through the oil may be provided if desired. The arrangement mentioned has been at present constructed for handling powers up to a maximum of about 2 kw. ; but it is probable that modifications would have to be introduced to enable it to be available for much higher powers. In connection with the operation of arcs of this type—*i.e.*, copper carbon arcs—it is interesting to note that it is not essential that the copper electrode should be positive, and the carbon negative, as is usually supposed,‡ and as is customarily the case, for example, with the Poulsen arcs, as advantages are often found in using the reverse connection. This is often more especially the case when difficulty has been experienced in starting up the arc and obtaining stable oscillations. Under these conditions a reversal of polarity will frequently cause strong oscillations to be set up, which persist when the polarity is again reversed back to the normal direction. The normal direction, copper positive, generally gives oscillations of more constant frequency than those obtainable if the polarity is maintained in the reverse direction.

* *Proc. Phys. Soc. Lond.*, 26, p. 372, June, 1914.
† See *Science Abstracts*, 16 B., No. 879.
‡ See, for example, *Barecca, the Electrician*, 60, p. 522.

When an arc is running in air there is always a burning away of the carbons ; if, however, the arc is placed in an atmosphere which is rich in carbon (hydrocarbon gases), the gas will be decomposed by the heat of the discharge, and carbon deposited on the arc electrodes. It is thus possible to have an arc in which the carbons " grow " instead of wearing away when in use. This is the case to a slight extent with the " oil-arc " described above, as when it is in use practically the only adjustments that are generally necessary (after the preliminary striking) are occasional movements of the electrodes further apart to compensate for the slight lengthening of the carbon rod.

[*Photo : C. Vandyck*

W. DUDDELL, F.R.S., WHO HAS CARRIED OUT MANY IMPORTANT INVESTIGATIONS WITH THE ARC, AND TO WHOM WE OWE MUCH OF OUR KNOWLEDGE OF SUCH OSCILLATORS.

It is obvious, however, that if the carbons wear away in some gases and grow in others, there must be some gas or mixture of gases in which these effects will exactly balance one another, and no adjustments of the arc should be necessary once the initial starting has been accomplished.

One such mixture is of acetylene and hydrogen (of which the relative proportions are best found by experiment). This mixture has been successfully employed in the Colin and Jeance apparatus, which will be described more fully below.

The same result could in all probability be achieved in the oil-arc (and similar apparatus) by the use of suitable liquids, or mixtures, instead of the oil at present employed.

The Colin-Jeance Arc Generator.

This arrangement, originally patented in 1909,* is in the main very similar to the Poulsen apparatus, in that it consists of three copper-carbon arcs connected in series, and burning in an atmosphere composed of a mixture of acetylene and hydrogen in such proportion that the normal wear of the carbon electrode is compensated for by the deposition of carbon from the gaseous atmosphere. The mixture of gases may be conveniently generated from mixture of calcium carbide and calcium hydride.

The usual supply voltage varies between 500 and 750 volts. The Colin-Jeance patent, referred to above, is, as far as I am aware, the first instance of the employment of an intermediate circuit tuned to the oscillation frequency for coupling the arc-

* British Patent, 18436, 1909.

shunt circuit on to the aerial circuit. This arrangement is often employed now in this and other apparatus as it enables better tuning to be obtained and a purer wave radiated. On the other hand, the majority of arcs produce oscillations which are seldom of constant frequency, so that under these conditions it is generally found that the aerial current is not of by any means constant strength, because if the arc frequency varies it quickly falls out of tune with the aerial circuit, and therefore the current in that circuit quickly falls off. The presence of the intermediate circuit aggravates this trouble, since it renders the relative tuning of the arc circuits and the aerial circuits much sharper. On the other hand, since the intermediate circuit enables a purer wave to be radiated it enables sharper tuning to be employed at the receiver, thus minimising interference from other stations and also from atmospheric disturbances since the coupling can then be weakened.

It may be as well to mention here (as it was omitted in the preliminary discussion of the arc methods of producing oscillations) that the frequency of the oscillations in the shunt oscillation circuit across the arc does not depend merely on the values of the inductance and capacity in that circuit, as it does in the case of the majority of spark transmitters, and in the cases of oscillations in closed metallic circuits. This is on account of the fact that the resistance of the arcs is not negligible as it is in the majority of the other cases. Moreover, the effective resistance of the arc varies very considerably with the arc length and arc current, as shown by the characteristic curves previously shown.

The complete expression for the oscillation frequency in a circuit containing Inductance, L henrys ; capacity, C farads ; and resistance, R ohms, is

$$n=\frac{1}{2\pi}\sqrt{\frac{1}{LC}-\frac{R^2}{4L^2}}$$

and it is therefore only when R is negligible compared with L that the frequency is given by the simpler formula $n=\frac{1}{2\pi}\sqrt{CL}$, which is the one most commonly employed. In this case n is a function of the arc length, etc.

To meet this case a formula has been devised by G. Nasmyth,* and is as follows :

$$n=\frac{1}{2\pi}\sqrt{\frac{1}{LC}-\frac{\left(R-\frac{c+ld}{A}\right)^2}{4L^2}}$$

Where n is the frequency L is the inductance in henrys, C is the capacity in farads, R is the resistance in the oscillation circuit in ohms, A is the current through the arc, l is the length of the arc, and c and d are constants depending on the nature of the arc electrodes, and on the nature of the gas surrounding the arc.

Hence it is evident that quite small changes in the arc length supply current, etc., will produce changes in the frequency of the oscillations. This variable frequency is one of the great drawbacks to most arc transmitters, and renders their successful operation for prolonged periods a matter of some difficulty.

The Dubilier Arc Generator.

This apparatus is similar in general outline to the ones previously described, with the exception that attempts have been made to render the apparatus as a whole

* *Physical Review*, 27, p. 117, 1908.

more portable, at least for the smaller powers. The arc is arranged to take place inside a closed copper cylinder, provided with means for adjusting the internal carbon electrode which forms the other arc terminal from outside the cylinder. The cylinder is generally fitted with radiating flanges to assist cooling. This arrangement usually renders water cooling unnecessary. A hydrocarbon atmosphere is employed, produced by the vaporisation of alcohol or methylated spirit, which is allowed to drip into the arc chamber when required, while a safety valve maintains the gas pressure approximately constant.

THE T.Y.K. ARC.

An interesting development of the arc oscillation generators has been made recently by some Japanese investigators, and is known as the "T.Y.K." system, from the initials of its inventors, W. Torikata, E. Yokoyama, and R. Kitsmura.* Its chief novelty lies in the materials used for the arc electrodes. These are made up from a pair of such substances as the following:

Silicon, ferro-silicon, carborundum, boron, magnetite, iron pyrites, molybdenite, etc. The combination of magnetite and brass is said to give on the whole the most satisfactory results. A continuous current supply at about 500 volts is usually employed. It would appear that this apparatus is merely another particular case of what is apparently an oscillating arc, but really seems to be a quenched short spark operating at the usual arc voltages. Further details of such effects will be given below, see pp. 25 and 26.

A curious point in connection with these oscillation generators is that the materials employed for the electrodes are also capable of acting as rectifiers of alternating currents, and, in fact, of forming wireless detectors. For instance, it has been shown by Dr. Eccles† that ordinary crystal contact wireless detectors can be utilised to set up electrical oscillations of feeble intensity in a suitable oscillation circuit connected across them. This T.Y.K. apparatus therefore seems to correspond to some such action as this, but on a much more powerful scale.

(*To be continued.*)

* British Patent, 10823, 1912.
† W. H. Eccles, *The Electrician*, 72, p. 1058, *ibid.* 66, p. 384, etc.

The Methods Employed for the Wireless Communication of Speech (iii)

By PHILIP R. COURSEY, B.Sc.

(Read before the Students' Section of the Institution of Electrical Engineers, on February 2nd, 1916.)

Short Spark Methods of Generating Oscillations.

The apparatus placed in this group is generally classed as producing trains of damped oscillations, which follow one another with great rapidity so that the group frequency is above the acoustic limit. This, as pointed out above, is not necessarily the case, and hence some writers often refer to them under the heading of "Arcs," so that it will be convenient to consider them here after having briefly reviewed the principal forms of arc generator. The question as to whether a given discharge is an arc or a spark is often rather a difficult one to decide, as the distinction between the two is not by any means always apparent to the eye even if the discharge is visible. The distinction between the two is more a matter of convention than of real difference in many cases, since one form of discharge readily merges into the other with little apparent change in its characteristics.

In the ordinary meanings of the terms, a spark is a definite disruptive breakdown of the dielectric between the two terminals by reason of the electric stress applied to the medium being greater than the critical breakdown value. The current which passes across the dielectric under these conditions is only momentary, and is carried by a few ions which generally arise from the material of the dielectric. An arc, on the other hand, is a sustained discharge through the dielectric, which therefore requires the provision of a plentiful supply of ions to form carriers for the current. In the majority of cases these ions are produced from the material of the electrodes, and often arise through chemical dissociation by reason of the heat generated.

If an arc discharge goes out the source of ionisation ceases as soon as the electrodes cool down again, so that if the electrodes are fixed it is necessary that the dielectric should be punctured by a spark before an arc discharge can be restarted between them, unless some exterior source of ionisation is provided. Hence, it is evident that an arc discharge cannot be maintained if a sufficient supply of ions is not available. If the electrodes are kept cool, or made of a material which does not readily yield ions, it will be difficult to start or maintain an arc discharge between them, and hence if a discharge take place at all between such electrodes it will tend to remain in the spark form, so that once a discharge has passed it cannot continue more than a very short space of time on account of the lack of ions to form the conducting path. Therefore it follows that a discharge gap of this form will be of the "quenched" variety —meaning that the discharge is quenched or extinguished very rapidly. Further, if the discharge is quenched out very rapidly it follows that the gap should be ready for

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Erratum.—On p. 95 of the May issue, *read* $n = \frac{1}{2\pi\sqrt{CL}}$ *instead of* $n = \frac{1}{2\pi}\sqrt{CL}$.

the passage of a fresh discharge a very short space of time after the first has passed, and hence this type of gap satisfies the requirements of being able to produce a series of discharges following one another very rapidly ; in other words, it should be suitable for the purposes of wireless telephony.

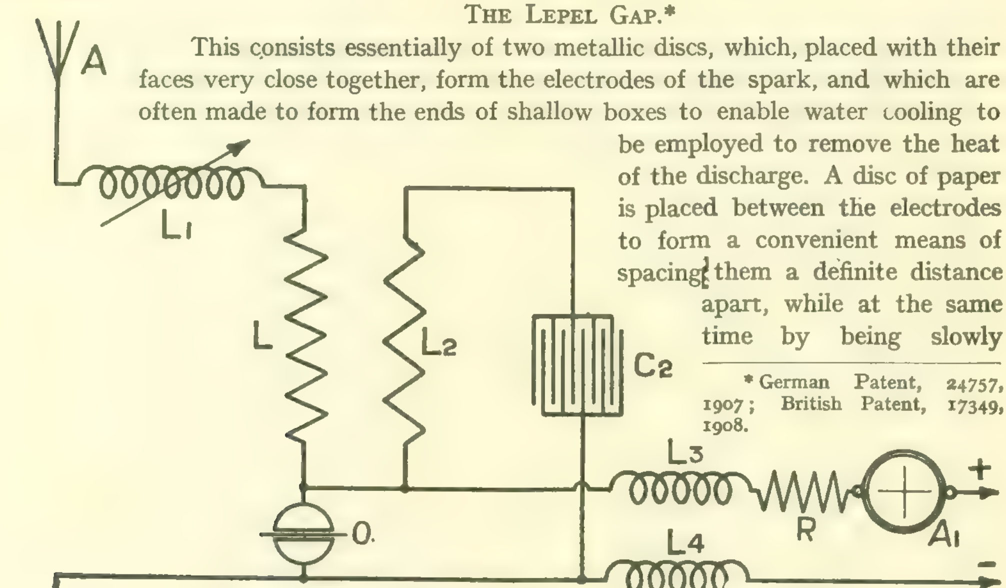
Spark-gaps of this kind form the basis of the Lepel, Telefunken, Peukert and other patents, and are based on the results of experiments of M. Wien on the quenching effect of short spark-gaps.

Of these gaps the Telefunken is most commonly used in practice with alternating current (of frequency about 500 per sec.) for the purposes of spark wireless telegraphy so as to obtain a good musical note. The Lepel gap is most commonly used on direct current, and under such conditions the spark frequency may be made very high, and is generally sufficiently so for use in wireless telephony.

Any of the forms of quenched gaps will yield a high spark frequency if connected to a suitable direct current source, and the electrical constants of the circuits are properly adjusted. The most important adjustments in this respect are those of the choking inductances in the main supply circuit, and also the value of the condenser in the oscillation circuit, since this capacity combined with the capacity between the plates of the oscillator itself, in conjunction with the choking inductance and series resistance, determines the "time-constant" of the charging circuit (charging the condenser between each spark), and hence also the spark frequency. That is to say, an increase in the choking inductance or in the series resistance will increase the charging time, and therefore lower the spark frequency, while a decrease in the capacity of the oscillation circuit condenser or of the capacity of the oscillator will raise the spark frequency.

THE LEPEL GAP.*

This consists essentially of two metallic discs, which, placed with their faces very close together, form the electrodes of the spark, and which are often made to form the ends of shallow boxes to enable water cooling to be employed to remove the heat of the discharge. A disc of paper is placed between the electrodes to form a convenient means of spacing them a definite distance apart, while at the same time by being slowly



LEPEL TRANSMITTER CONNECTIONS.

FIG. 9.

* German Patent, 24757, 1907; British Patent, 17349, 1908.

burnt away it furnishes a hydrocarbon atmosphere in the discharge gap, which improves its operation.

The thickness of paper most commonly employed is from 5 to 10 mils. (0·005 inch to 0·01 inch), but, of course, varies somewhat with the supply voltage. The latter is generally about 400 to 500 volts D.C.

When in operation the gap should be connected in series with suitable choking inductances and resistances to limit the flow of current from the supply mains, and also to determine and regulate the spark frequency. The oscillation circuit is connected in shunt across the gap in the usual manner. Usual diameter of discs = 3 inch to 5 inch.

A spark frequency of the order of 10,000 per sec. or more can usually be obtained.

The discharge that takes place in the gap is often described as an arc rather than as a spark, and the improvement that is stated to result from the hydrocarbon atmosphere, resulting from the decomposition of the paper ring separating the electrodes, perhaps lends support to this view. It is probable that the discharge really partakes of the nature of both the spark and the arc, and is intermediate between the two types.

The Telefunken Spark-Gap.*

This spark-gap is very similar to that of von Lepel, just described, and operates in the same manner. The chief points of difference in the most usual constructions are the use of mica ring separators between the copper disc electrodes instead of the paper employed in the Lepel gap ; and the use of a number of gaps in series in place of the usual one, or at most two, in the Lepel arrangement. This means that higher voltages must be employed, with consequently a great power output. Air cooling of the discs is also generally resorted to instead of water cooling.

The Peukert Oscillation Generator is similar to either of the above with the exception that oil is employed as the dielectric, and it is kept in circulation by the rotation of one of the discs. This dispenses with water cooling.† The discs are usually spaced about 1/250 inch apart. Direct current at 500 to 600 volts is employed. The discs are silver-plated copper.

A somewhat similar arrangement to the Telefunken gap has been employed by Ditcham in some recent experiments. Successful telephonic communication has been carried on by their use for distances up to about 100 miles.

A number of spark-gaps are used in series on a supply voltage, direct current of from 1,000 to 2,000 volts. (See *The Electrician*, Vol. 72, p. 569.)

Recent experiments with oscillations produced in this manner by means of short-quenched spark oscillation generators have shown that they may probably prove to be of considerable value for the generation of oscillations suitable for the uses of wireless telephony.

By investigation of the oscillations produced by the spark-gap, by means of a Braun cathode ray tube, it has been shown that under certain conditions a short spark-gap between brass and aluminium or other metallic electrodes placed in an atmosphere of coal gas, and supplied with direct current at about 400 volts through suitable choking

* German Patents, 27164, 1908 ; 27483, 1908 ; 28198, 1908 ; also British Patent, 6424, 1909.

† See *The Electrician*, Vol. 64, p. 550, 1910 ; see also J. A. Fleming and G. B. Dyke, *Proc. Phys. Soc. Lond.*, 23, p. 117, for description of similar spark-gap.

inductances and resistances, is capable of yielding practically undamped oscillations; this means that the spark frequency must synchronise with the oscillation frequency, so that impulses are supplied to the oscillation circuit exactly in phase with the oscillations at periods which cannot be further apart than about two or four half-waves of the oscillation current, so that the amplitude of the oscillations is maintained practically constant. It may perhaps be emphasized in this connection the excellent manner in which the phenomena which takes place in such oscillation circuits may be shown up and studied by means of the Braun cathode ray tube, previously mentioned. The effect of varying the capacity in the circuits or the choking inductance, etc., may be investigated very easily, and the best effects obtained by proper adjustments. Some interesting experiments on this subject have recently been carried out by H. Yagi on the production of undamped oscillations from an aluminium-brass spark-gap.*

The Marconi Disc Discharger for Generating Undamped Waves.

Another form of spark discharger by means of which it is possible to generate undamped waves is the Marconi multi-disc discharger.† The arrangement of apparatus is very much that of the usual Marconi studded disc discharger fed from direct current.

In this instance, however, the spark frequency is arranged to be much higher than the usual, and at the same time a number of such discs are arranged on the same shaft, with their studs or contacts so displaced relatively to one another that the sparks will occur on successive discs at regular intervals during the spaces on the first disc. Each disc is preferably arranged to discharge through its own condenser and oscillation circuit, independent of the others, the effects of them all being summed up in a secondary circuit connected to the aerial in the usual manner.

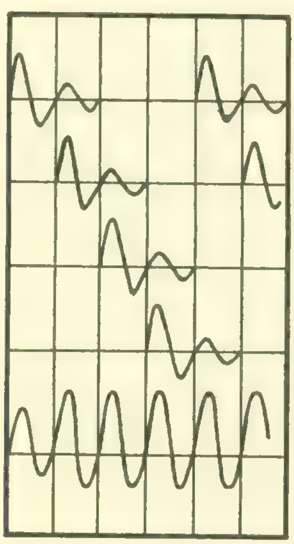


DIAGRAM OF MODE OF OPERATION OF MARCONI MULTI-DISC DISCHARGER.

FIG. 10.

If now we so arrange the oscillation frequency of each circuit that one complete wave (or at the most two) of current takes place in the interval between the spark on one disc and the next spark on the next disc, the effect of the second spark will reinforce that due to the first, and the oscillations will be maintained.

If the sparks take place every complete wave the oscillations will be to all intents and purposes undamped; but if every second wave, there will be a slight diminution of amplitude every alternate wave—much as may probably be the case

* H. Yagi, *The Electrician*, 76, p. 195, Nov., 1915.

† Wireless World, 2, p. 75, 1914.

with some of the short spark dischargers, described above. Such an arrangement should be capable of dealing with considerable power if properly designed, while the oscillations produced would be eminently suited for wireless telephony. The system, in fact, amounts to an attempt to accomplish in a regular mechanical manner what happens in effect in some of the short quenched spark dischargers—*i.e.*, to ensure that each fresh impulse due to the passage of a spark shall exactly synchronise with the existing oscillations in the circuit. To a considerable extent this occurs automatically in the short spark methods by reasons of the reactions which take place between the currents in the various circuits; but, nevertheless, some irregularities will generally occur. The great objection to the mechanical method, apart from the difficulties of the high speeds required for the discs, is the difficulty of maintaining the discs running at a perfectly definite and constant speed. This is essential if the method is to work properly in order that the successive impulses shall synchronise properly with one another. It renders imperative some very sensitive form of speed governor that will maintain the discs running at a constant speed.

VACUUM OSCILLATION GENERATORS.

In 1884 Edison showed that an incandescent filament of carbon (such as a lamp filament) possesses the property of ionising the surrounding air, so that it becomes a unilateral conductor.*

This property has been turned to practical utility by Dr. Fleming and others, and forms the basis of the well-known Fleming oscillation valves which are now often used as wireless detectors. Some of these values have characteristics (*i.e.*, volt-ampere curves) which at some point are negative, like an arc characteristic, and hence it is possible to use such valves as generators of oscillations just as the arcs can be so used.

The use of a third, or " grid " electrode, as it is generally called, as in the de Forest " Audion " and others, leads to considerable advantage from the point of view of their operation as oscillation generators.

The mode of operation of this type of apparatus may be briefly summarised as follows: The hot filament has the property of emitting negative electrons, and hence the combination of hot filament and cold plate in an exhausted vessel forms an electrical conductor, which will allow current to flow in one direction only—that is to say, it is a unilateral conductor, and therefore will exert a rectifying action on an alternating P.D. applied to it. Since the current passing through this vacuous space is carried by a stream of moving electrons, and since an electron is merely a negative electric charge, it is evident that the motion of the electrons can be influenced either by an electro-static or by a magnetic field, and therefore the strength of the current flowing between the filament and the plate can be varied by subjecting the electron stream to electric or magnetic fields arranged so as to deflect the stream off, or partially off, the plate.

As shown in Appendix 2, for the conditions usually met with in oscillation valves the electric deflection will produce greater effects than the magnetic. Hence its use in practice for this purpose. If it is desired to influence the electron stream by an electric field, the point to which the deflecting potential is applied should obviously be placed as close to the electron stream as possible. Hence the " grid " electrode in the " audion " type valve is placed right in the path of the

* See J. A. Fleming, *Proc. Royal Institution*, 1890.

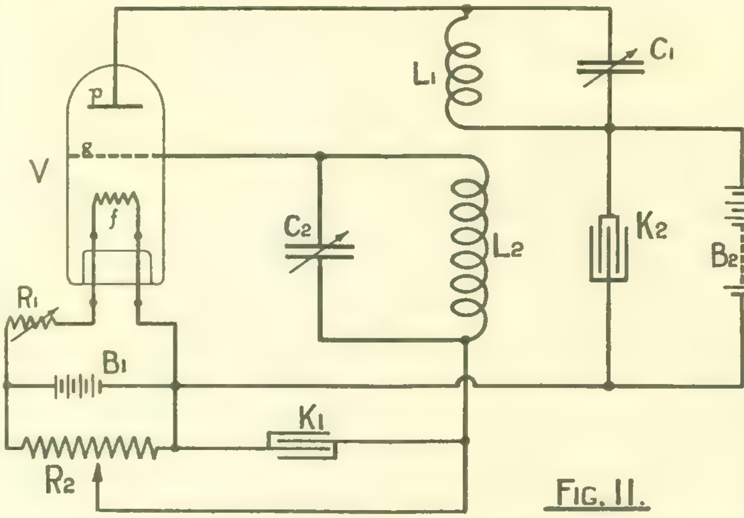


FIG. 11.

electrons between the filament and the plate, so that a small P.D. applied between this grid and the filament will cause large variations in the current flowing to the plate. The Marconi Co. have, however, shown* that it is possible to have the third electrode of the valve outside the glass bulb instead of inside, so that this should lead to a simplification of the construction. In general, however, this method of construction is not so effective as when the " grid " is placed inside the valve, and in the path of the electrons between the filament and the plate. This renders it possible to use this type of valve as an amplifier and consequently as an oscillation generator, for if we apply a small oscillatory P.D. to the grid circuit the above action of the valve as an amplifier will result in a magnified oscillation in the plate circuit. By arranging this magnified oscillation, to be further magnified by repeatedly passing through the amplifier, its amplitude will be continually increased until a steady state is reached. In this manner fairly powerful oscillations may be set up which may serve for use in wireless telephone transmission.

They possess the great advantages of simplicity and of reliability of operation; but since the forms at present constructed are only capable of handling relatively small powers, it is necessary to utilise a considerable number of them in parallel in order to obtain sufficient energy.

In fact, in the most recent long-distance tests with this method as many as from 300 to 500 of such oscillation valves, or " audions," were used in parallel. Successful speech was obtained across the Atlantic from Arlington, Va. (U.S.A.), to the Eiffel Tower, and also from Arlington to Honolulu, a distance of 5,000 miles.

A difficulty that arises when attempting to construct larger models of these valves to handle heavier oscillatory currents is the rapid disintegration of the hot filament by the ions, etc., shot off from it, and by the extra heating that is caused by the large oscillatory currents passing through it, and through the vacuous space. The electronic bombardment of the grid and plate may also give rise to considerable heating unless means are provided for keeping them cool.

The Marconi Co. claim in some recent patents† to have overcome this difficulty to a very great extent by the use of a platinum tube inside the valve, the tube being heated by internal carbon filaments, thus avoiding the sealing in of very large con-

* Marconi Co., British Patent, 13247, 1914.

† See, for example, British Patent, 6476, 1915.

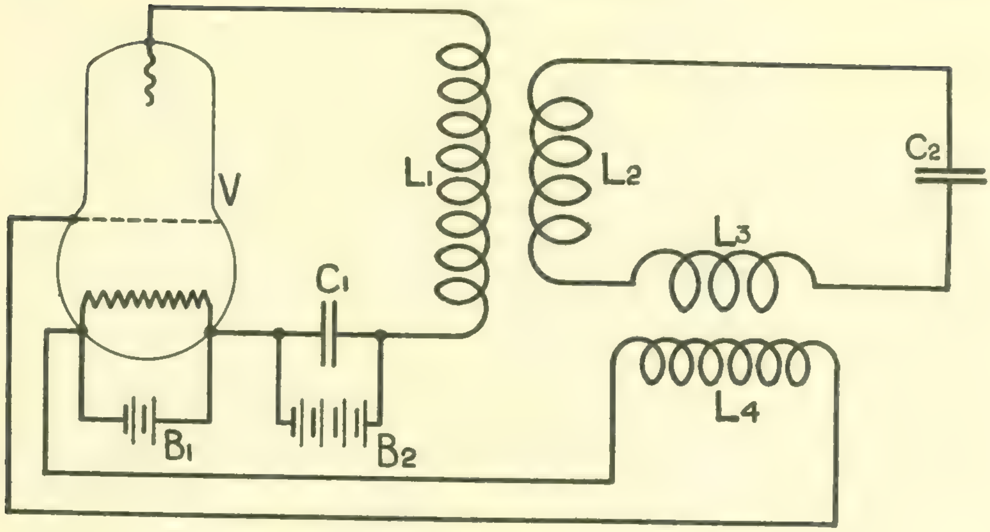


FIG. 12.

ductors to heat the large mass of platinum inside the valve, while at the same time the large surface of the platinum tube prevents its rapid disintegration.

The use of a coating of lime on the incandescent filament has been shown, by Wenelt* and others, to yield a much greater conductivity of the vacuous space ; that is, the heated lime promotes the emission of a copious supply of electrons from the cathode, or heated electrode. R. S. Willows† and others have described some interesting experiments which bring out the advantages to be obtained from its use, and also from the use of heated aluminium phosphate on the anode (which substance J. J. Thomson has shown emits positive ions when it is heated). It might, therefore, be expected that the use of these substances in the vacuum oscillation generators would lead to greatly improved operation of the same, but very little work seems to have been done in this direction. A serious disadvantage, however, appears to be loss of vacuum due to emission of gas.

O. Tugman‡ has investigated the effects of gas pressure and electrode spacing on the operation of these vacuum valves and has arrived at some valuable conclusions which should also be applicable to the cases we are considering, viz.—of oscillation generators.

Within the last year the results of a considerable amount of experimenting in this direction have been published in America by Langmuir§ and Dushman||, and it has been found that greatly improved results may be obtained by using very much higher vacua—so much so that the name of "kenotron" (from the Greek κενος, an empty space) has been given to the oscillation rectifiers that they have constructed. They have used the name "pliotron" (Greek πλειον "more") to designate the oscillation amplifiers having the third or "grid" electrode. These may also be used as oscillation generators. These generators are apparently capable of handling consider-

* *Annalen d. Physik*, 14, p. 425. † *The Electrician*, 68, p. 302. ‡ *Physical Review*, 29, p. 154.
§ I. Langmuir, *Proc. Inst. Radio Engineers*, April, 1915.
|| S. Dushman, *The General Electric Review*, May, 1915.

able powers owing to the fact that the high vacuum enables much higher voltages than the usual to be employed.

For this purpose they have suggested a combination of the two types of valves—viz., one a high voltage rectifier (kenotron), to rectify a high voltage A.C. supply which may then be used to supply a high voltage direct current to the pliotron oscillation generator. The initial high voltage is most easily obtained by this arrangement from a step-up transformer run off an ordinary A.C. supply circuit. This method apparently represents a considerable advance on previous apparatus of this kind.

As mentioned above, all apparatus of this class possesses great advantages over the arc and similar methods of oscillation generation, on account mainly of the relative simplicity of the apparatus and of the ease and reliability of its operation, coupled with the fact that practically no attention or adjustment is required beyond the initial switching on. The large range of frequencies obtainable from them and the ease of adjustment of the frequency also give them further advantages over the frequency raising apparatus, which we shall consider later, while, in addition, the oscillations obtained in this manner are much steadier and of more constant frequency than those from any existing form of arc generator. The fact that the same type of apparatus is available for both transmitting and receiving should also lead to a considerable simplification of the construction of the plant necessary at wireless telephone stations equipped on those lines, and corresponding economies in their operation and maintenance.

[*Photo: Frank C. Perkins.*

MR. THEODORE N. VAIL SPEAKING BY WIRELESS TELEPHONE FROM NEW YORK TO MARE ISLAND, CALIFORNIA, 2,500 MILES AWAY.

The Methods Employed for the Wireless Communication of Speech (iv)

By PHILIP R. COURSEY, B.Sc.

(Read before the Students' Section of the Institution of Electrical Engineers, on February 2nd, 1916.)

Alternators and Frequency Raising Apparatus.

Owing to the extreme difficulty, which amounts almost to an impossibility, of designing and constructing an alternator of any of the usual types which shall be capable of generating an alternating current of the frequencies required in wireless work, attempts have been made from time to time to construct "frequency raisers" which shall be capable of raising the frequency of an alternator or other source, so as to bring it within the wireless range. This branch of the subject has recently been treated very fully by A. N. Goldsmith, so that only a brief abstract of the most important features will be given here.*

Frequency raiders as a whole may be broadly classified into two main divisions:—

(1) Frequency adders,

(2) Frequency multipliers.

To the first class belong most of the machine or alternator type of frequency raisers, while under the second are included the "static" frequency raisers, etc.

The distinctions between the two classes will be more apparent after a further consideration of the different methods by which the frequency of a current can be raised.

In the case of an ordinary (single-phase) alternator, the most usual construction is to have the fixed "armature" windings on the stator and the magnet windings on the revolving rotor. The frequency of the currents generated by such a machine depends then merely on the speed of rotation of the magnet system on the rotor and on the number of poles on it. A simple consideration then shows the practical impossibility of constructing a machine of this type to generate currents of wireless frequency with any available power (see Appendix I.).

Suppose, however, that instead of supplying the rotating field winding of our alternator with direct current, as is usual, we produce a rotating field by means of alternating currents—just as in the stator of an induction motor—and arrange the direction of rotation so that it is in the same direction as the direction of mechanical rotation of the rotor (and field windings). The magnetic field will then have a speed of rotation in space equal to the sum of the speeds of rotation of the field and windings separately.

The frequency of the currents that will be generated in the stator conductors will, therefore, depend on this speed, instead of merely on the speed of mechanical rotation, assuming the same number of poles on the fields in each case. In other

* See *Proc. Inst. Radio Engineers*, June, 1915; also *Electrician*, 75, p. 461, and p. 508, 1915.

words, we have here the essentials of a machine for raising the frequency of a given supply current.

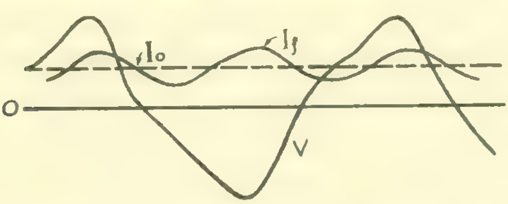
It is evident that a number of such machines could be connected in series, and the fields of one supplied from the generated currents of the previous one, and thus the frequency can be gradually raised from low values to high ones.

One of the best known frequency raisers which is of the alternator type is known as the *Goldschmidt Alternator* and consists essentially of an induction motor or alternator which performs the functions of raising the frequency by the method outlined above, but with the distinction that all the successive increments of frequency are arranged to take place in the one machine instead of in a number of such machines connected in series. It is well known that a single-phase alternating current can be resolved into two equal and oppositely rotating periodic quantities.

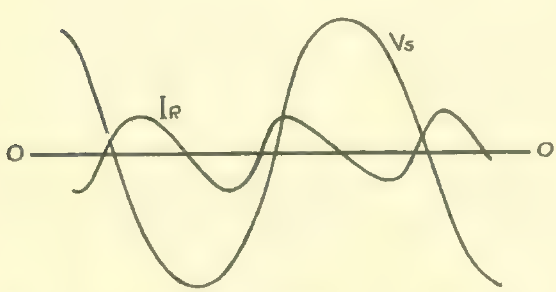
This explains the occurrence of the double frequency current observed in the rotor of a single-phase induction motor when it is driven at synchronous speed (slide, oscillogram), and also the double frequency ripple that is often observed on the field current of alternators.

In the Goldschmidt machine this double frequency ($=2n$) current is allowed to flow in a tuned circuit, and so attains considerable magnitude. By the same reasoning the field, due to this current, may be resolved into two oppositely rotating magnetic fields; as, however, the complete rotor is revolving with a speed corresponding to the frequency $=n$, one of these components has a speed relative to the stator of $2n-n=n$; and the other of $2n+n=3n$. This latter, therefore, gives rise to currents of three times the fundamental frequency in the stator windings, which can be isolated by means of a tuned circuit. The other component of frequency, n, merely augments the original currents of the fundamental frequency in the stator windings. This action can be repeated a number of times, each one giving an addition to the frequency, and being confined to its own tuned circuit, while the last is connected directly to the aerial and earth through the appropriate tuning inductances.

Machines have been



OSCILLOGRAM SHOWING DOUBLE FREQUENCY RIPPLE ON FIELD CURRENT



DOUBLE FREQUENCY CURRENT IN ROTOR OF INDUCTION MOTOR AT SYNCHRONOUS SPEED.

FIG. 13.

constructed on these lines up to outputs of about 250 kw., and have been successfully employed for Transatlantic communications over distances of about 3,000 miles, but only as yet for telegraphic purposes, on account of the great difficulty of constructing a microphone to deal with the heavy antenna currents. (See section on Microphones.) An additional feature of these machines is the possibility of modulating their output by control of the field current, which, of course, only amounts to a small fraction (=from 5 to 10 per cent.) of the output of the machine. This leads to considerable simplification of the control apparatus, but it is not as yet proved whether this method is available for the higher powers of the larger machines.

It should be remembered, however, that all machines of this type suffer from the great disadvantage that they are frequency adders, and not frequency multipliers; and hence, if the initial frequency is not fairly high compared with the final one, such a great number of stages would be required that the arrangement would hardly be of much practical value from the economic standpoint. With frequency multipliers, however, the case is very different, and a rapid increase of frequency can be much more readily obtained.

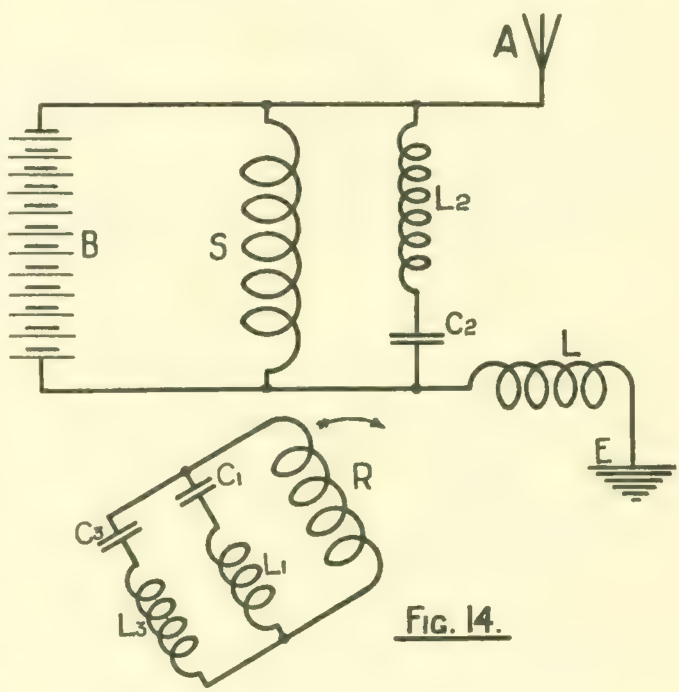


FIG. 14.

We now turn to the second class of frequency raisers—that is, frequency multipliers. The most important representatives of this class are the transformer frequency raisers, in which use is made of the fact that the magnetising current of a transformer working on a sine wave E.M.F. is generally very far from a sine curve.

The exact shape of this current curve depends on the state of magnetic saturation of the magnet core, and may be varied, within limits, to suit the requirements. The Fourier analysis of the above current curve shows that there is a prominent third harmonic present in the current wave. This will generally be found to be the case.

It is possible by suitably designed tuned oscillation circuits to strengthen this third harmonic by resonance, and therefore to obtain from a given A.C. E.M.F.

of approximately sinoidal wave form a current of three times the frequency of the original supply. This current may be utilised in a similar manner to produce another of three times its own frequency—*i.e.*, nine times the initial frequency, and so on.

Comparing this method with the frequency adders, previously described, it is seen at once that a very much more rapid multiplication of the frequency is obtained, thus three stages would raise the frequency twenty-seven times. The great limitation to this method is that it is not very easily adaptable to handling large powers, since the magnetising current of a transformer is quite small ; while if much load is put on, the current becomes more sinoidal in shape, so that the triple frequency output is diminished.

If we superimpose both an alterating magnetisation and a steady magnetisation on to a transformer core it will be found possible to so arrange matters that the flux wave becomes unsymmetrical.

This indicates the presence of prominent harmonics which may be tuned out by appropriate circuits ; or, better, two such transformers may be connected up in opposition in such a manner that the fundamental or supply frequency cancels out in the secondary windings, leaving only a double or triple frequency harmonic which may be strengthened by resonance.

Mr. A. M. Taylor* has shown that it is possible to obtain a frequency increase as much as 27 : 1 by employing special arrangements with multiphase A.C. supply.

The greatest utility for these " static " frequency raisers, as they are often called, is obtained when they are used in combination with moderately high frequency alternators—*i.e.*, alternators designed for frequencies of, say, from 5,000 to 10,000 cycles per second.

Such alternators can be constructed with comparative ease, while an increase of their frequency of, say, nine times will gener-

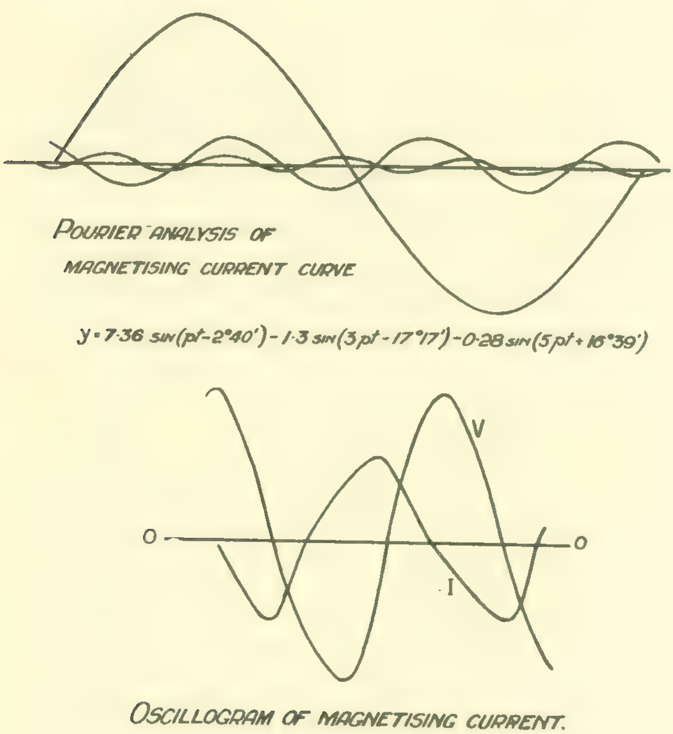


FIG. 15.

* *Journal Inst. Elec. Engineers*, 52, p. 700.

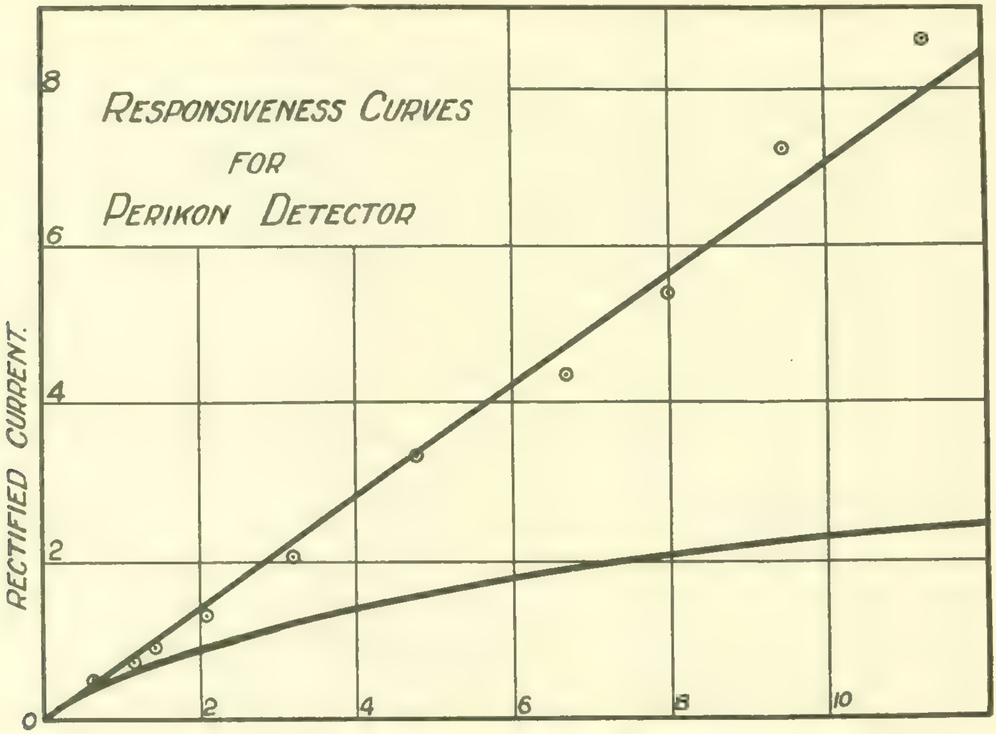


FIG. 16.

ally be found sufficient for long distance (long wave) wireless telephony; but, if necessary, a 27-fold increase, or more, may be used if desired for shorter wave-lengths.

MODULATION OF THE TRANSMITTED WAVES.

We have been considering up to the present the various means by which the required oscillatory energy may be generated. This leads us to the important question of how this energy is to be modulated in accordance with the speech waves. This is a matter that still affords one of the greatest difficulties in the development of the subject, although many attempts have been made towards its solution, some of which would seem to show considerable prospects of success.

In the first place the ordinary commercial carbon microphone is designed and constructed to carry only a fraction of an ampere, although experiments show that the commercial "solid back" type of transmitter is capable of carrying and modulating currents up to about 1 ampere or a little over. When larger currents have to be dealt with several such microphone transmitters may be connected in parallel, and arrangements made for them to be influenced simultaneously by the voice. It is generally inadvisable, however, to employ more than about five or six in this way, owing to inequalities in their operation causing the currents to be unequally divided between them, resulting in a loss in efficiency and in the purity of speech transmission,

apart from the difficulty of arranging for them all to be equally operated upon by the sound waves. In any case, however, it is obvious that the ordinary carbon microphone is useless for anything except the smallest of stations in which the aerial current does not exceed a few amperes. A further difficulty arises from the fact that, because a microphone can *carry* the desired current without undue heating, it does not at all follow that it will be able to successfully *modulate* it, although when used on the ordinary telephone circuits it may be quite efficient. This arises from the different conditions of use, and, of course, applies equally to other forms of microphone as well as to the carbon microphones ; as in the wireless case we have in general a much greater voltage available in the aerial circuit (than in ordinary circuits), and hence a correspondingly greater resistance variation is necessary for successful operation. Hence a low resistance microphone, with correspondingly small resistance variation (when spoken to), may be quite useless as a transmitter, although it may be able to carry the required current quite easily. Hence it is often necessary to connect more than one microphone in series to obtain sufficient resistance modulation. Another difficulty that frequently arises when using commercial microphones not specially designed for use with high frequency currents is that of capacity currents within the microphone shunting a portion (often a large portion) of the current across the frame or other parts of the instrument without their passing through the resistance material at all. For this reason it is often necessary to remount the parts of commercial microphones on insulating supports and frameworks, if the best effects are to be obtained from them when they are used for modulating high frequency currents.

An improvement may often be effected under these conditions by coupling the microphone to the antenna circuit instead of inserting it directly in the circuit, as by this means the effective voltage in the microphone circuit may be easily varied to suit circumstances, while at the same time the effect of the microphone on the aerial circuit can be controlled at will.

It is for this reason that it is generally advisable when a number of microphones are in use at the same time to arrange them so that they can be easily connected in parallel, in series, or in series-parallel, so as to obtain the best results in any particular circumstances. On account of the above limitations of the ordinary carbon microphone many attempts have been made to employ some other microphonic material which shall be capable of carrying much heavier currents without undue heating, and at the same time of successfully modifying them according to the sound waves. Attempts have also been made to modify the carbon microphone so as to render it more suitable for the work that it is required to do, and at the same time to render it possible to employ water cooling.

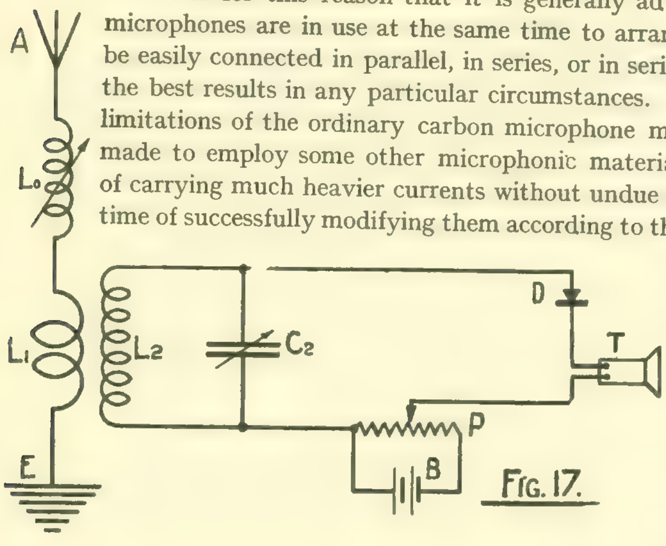


FIG. 17.

An example of a microphone transmitter of this type is furnished by Dubilier's transmitting relay microphone.

A much more successful type, however, is that employing some liquid as the current carrying medium, as it is then possible to employ a continuous circulation by which the liquid can be kept cool, and as it is only carrying the current for a short period of time while it is between the microphone electrodes. Two well-known forms are Vanni's liquid microphone and Chambers's liquid microphone.

In Vanni's microphone a fine jet of acidulated water or other convenient electrolyte is allowed to impinge on to a slanting metallic plate which forms one electrode of the microphone. Another plate carried by the diaphragm is arranged just to dip into the stream of liquid as it falls on to the other fixed plate, thus leaving a small space between them, the thickness of which is varied by the motion of the diaphragm.

This diaphragm may be operated directly by the voice, or preferably electromagnetically from a local circuit containing an ordinary microphone transmitter and suitable cells. The microphone should be inserted in the aerial circuit, or circuit coupled to it, rather than in the main supply to the arcs, or other oscillation generator on account of the reduction of electrolysis, and polarisation troubles when the microphone is traversed by an alternating current.

In Chambers's microphone the diaphragm is arranged to form one of the electrodes, while the jet of liquid impinges on its under surface. Hence the vibration of the diaphragm varies the thickness of the film of liquid issuing from the jet, and hence varies the resistance, in a manner depending on the sound waves.

It is stated that this type of microphone gives a very good speech reproduction free from resonance effects from the natural period of the diaphragm, since the liquid in contact with the diaphragm forms a very efficient damping agency preventing such free vibrations.

More recently another type of liquid microphone has been patented * in which the resistance variation is affected by varying the amount of conducting liquid admitted into a stream of non-conducting liquid flowing past the microphone electrodes; but as far as I am aware no extensive tests have been made with it to examine its capabilities.

Another rather novel form of microphone suitable for wireless telephony which has been employed for communications over considerable distances is Mazi's carbon powder microphone, in which the microphone material is carbon powder, a stream of which is passed through the apparatus so as to keep it cool.

As another method of modulating the transmitted waves mention should be here made of the condenser microphones, in which the diaphragm is arranged to vary the capacity of a condenser by means of its vibration. This condenser is con nected in the aerial circuit, and hence when its capacity varies with the sound waves the wave-length of the circuit will be altered and the aerial thrown in and out of tune with the other circuits of the transmitter (and receiver), and hence the strength of the transmitted waves will be varied by the movements up and down the resonance curve. This type of microphone has apparently not been applied to stations of any

* British Patent, 7922, 1914.

but small power, so that its possibilities cannot very well be gauged, except in that one would expect that considerable difficulty would be experienced in designing such a microphone to have sufficient area and capacity to carry the large aerial currents and at the same time to have sufficient spacing between the opposite electrodes to withstand the voltage and yet be small enough for the motion of the diaphragm to have any appreciable effect on its capacity.

RECEIVING APPARATUS.

The receiving apparatus required for wireless telephony by means of ether waves differs very little from the ordinary receivers in common use for wireless telegraphy, and hence need not be considered very fully here. The circuit arrangements at the receiver are much as usual for the particular detector employed. As to the detector, the really essential feature is that its indications should be practically proportional to the energy received, otherwise the speech would be distorted. It must also of necessity be suitable for use with a telephone receiver.

The type of curve required is the straight line one there shown.

These considerations rule out practically all of the "coherer" type of detectors (apart from their relative insensitiveness compared with other forms), and we are left with magnetic detectors, crystals, and valves, and similar detectors.

Of magnetic detectors the most important is the well-known Marconi magnetic detector.

Among crystals most of the usual combinations are available, the most suitable being, perhaps, the "perikon" (or zincite-chalcopyrite), zincite-bornite, carborundum, etc. The usual connections may be employed.

In general it is found that the use of a fairly weak coupling is advisable in order to obtain purity of speech-transmission. Under the heading of valves we have the Fleming valve, the de Forest "audion," and other similar detectors.

The connections of the receiving apparatus for use with the valve are essentially the same as when a crystal is employed except for the addition of the cells for heating the valve filament.

With the audion type of detector containing a third electrode slightly different connections are required, although the main features are the same.

This brings us to a consideration of the use of amplifiers in receiving, a practice which has lately grown in favour for wireless telephone receiving, as by this means it is possible to employ very much less power at the transmitter for a given range, an important factor in the present stage of development of the transmitting apparatus.

The available amplifiers may be classified for our present purposes into :—

(1) Electromagnetic or microphonic type.

(2) Electron or vacuum amplifiers.

The former include such apparatus as the Brown telephone relay, the telefunken, and other sound intensifiers, etc., and are available only for use in conjunction with one of the forms of detector previously mentioned. The mode of operation of all the members of this class involves the employment of some form of microphonic contact or contacts (such as a carbon microphone, or the microscopic air-gap of Brown's relay), the resistance of which can be controlled by an electro-magnet

through which is passed the " rectified current " from the detector.* Brown's relay, which may be taken as typical of this class, was described in a paper read before this Institution, and so need not be described in detail here.†

To the second class belong the vacuum amplifiers, in which use is made of the properties of cathode rays (streams of electrons) in a vacuum tube, as described above in connection with the vacuum oscillation generators. The " audion " and " pliotron " belong to this type. The Marconi Co. have also utilised amplifiers similar to the above in tests carried out with their apparatus by the Italian Navy in which distances of about 45 miles have been covered with an expenditure of energy at the transmitter of only 4 or 5 watts.

* The term " rectified " is used in the general sense to include the current yielded by the detector, whether or not it is a " rectifier " in the true sense of the word.

† *Journal Inst. Elec. Engineers*, 45, p. 590, 1910

The Methods Employed for the Wireless Communication of Speech (v)

By PHILIP R. COURSEY, B.Sc.

(Read before the Students' Section of the Institution of Electrical Engineers, on February 2nd, 1916.)

Summary of Results Achieved.

BEFORE concluding, it may be as well to briefly summarise the most important results that have been achieved :—

About 1906 Fessenden telephoned wirelessly over distances up to about 20 miles, with successful results, employing a small H.F. alternator for generating the oscillations. (It has been stated that he covered much greater distances by the same method at a later date.) Since then numerous tests have been made from time to time, mainly with various forms of arc generator, and some fairly considerable distances have been bridged, the most notable being :—

Poulsen's communications over a distance of about 150 miles in 1908.

Majorana's over distances of about 250 miles, and recently Vanni's between Rome and Tripoli, about 600 miles.

In most cases, however, up to the present, the apparatus employed has hardly been in a fit state for commercial use, owing largely to the considerable amount of skilled attention that is required for its operation, accompanied by the difficulty in most cases of relaying the transmitting microphone on to the existing land lines, so as to enable it to be made use of by ordinary telephone subscribers.

Although up to the present time the various forms of arc generator have proved to be the most successful means of generating the required oscillatory currents, more especially when large powers have to be employed, they require on the whole much more attention in use than do the other methods.

Although high frequency alternators (including the Goldschmidt reflection alternator and similar machines) require little attention in running, beyond that usually given to moving machinery, and in spite of their being essentially a " power proposition " of the type one would think suitable for the results required, yet their great cost of construction and installation will most probably mitigate against their extensive adoption on a commercial scale, especially in view of the frequent and extensive repairs which, up to the present, have proved necessary in all machines of this type which have been constructed.

On the whole, the most promising pieces of apparatus yet devised seem to be the new " valve " or " vacuum " generators of the " Pliotron " type, as no care or attention whatever in maintenance should be required, and the constructional and installational cost should compare very favourably with machine generators—whether they will yet be available for larger powers of several hundred kilowatts remains to be seen—but, apart from actual constructional difficulties, there would seem to be little against their use for such outputs.

Their employment in wireless telephony is at present limited to the use of a large

number in parallel, as has already been described. They have, however, enabled the record for long distance wireless telephone communications to be completely broken by the recent Transatlantic communications, and also those between Arlington and Honolulu (5,000 miles).

The employment of this type of apparatus should lead to considerable simplification of both transmitters and receivers, and would tend to make the apparatus suitable for use by " unskilled " persons, as practically nothing requires to be done beyond the initial switching on of the transmitter, while, in addition, the " microphone " problem of successfully modulating the radiated energy would be largely solved, as their very nature permits of such ready control of the oscillatory output by means of the potential of the " grid " electrode, and of the heating current of the filaments, as has been shown in the long distance communications referred to above, when the transmitter was relayed on to the land lines from New York.

As at the receiver the same type of instrument is available for amplification purposes it should easily be possible to relay the received speech on to land lines—an advantage which would be of considerable commercial value in connection with long oversea transmission.

One great difficulty that will have to be overcome if these generators are to be made for large powers is the disintegration of the filaments by the large oscillatory currents passing to and from it ; but it is yet too early to speculate as to what effect this may have on the development of these oscillation generators.

In conclusion, wireless telephony, although an extremely interesting and important development of wireless signalling, will probably never have the extensive application that wireless telegraphy has already attained, but, nevertheless, it has a sphere of utility of its own when the apparatus can be rendered sufficiently " commercial " and reliable in form to be left in unskilled hands, just as can an ordinary wire telephone instrument. Probably its most important application will be to long distance oversea communications which cannot be carried on by submarine cables, its great advantage being that there is no *distortion* of the speech with distance (as in ordinary line transmissions) but merely *attenuation*. Its other important field will be in ship to ship and ship to shore communications for emergency, distress and similar purposes where the rapidity of communication of the desired intelligence (such as the position of a ship in distress, etc.) is all-important For general communication purposes, however, between ships it is doubtful if it will ever supplant the wireless telegraph, but will remain as an auxiliary to it, for use on such occasions as above.

Finally, I should like to add that it has not been possible, in the limited time available, to do more than sketch out the merest outline of the subject before us ; and also to take the opportunity of expressing my best thanks to the Marconi Company for the loan of photographs illustrating their apparatus, and to Messrs. Crosby, Lockwood & Co., for permission to reproduce certain illustrations appearing in their publications.

APPENDIX I.

CALCULATIONS FOR ALTERNATOR FOR THE DIRECT GENERATION OF CURRENTS OF WIRELESS FREQUENCY.

Suppose we require to generate a current having a frequency of 200,000 cycles

per sec., which corresponds to a wave-length of 1,500 metres. Assuming an alternator of the usual type, we have: frequency = (revs. per sec. of the rotor) x (number of pairs of poles), so that if D is the diameter of the revolving rotor in feet, and P is the maximum permissible peripheral speed in feet per min. consistent with mechanical stability; we have N = revs. per min. $= \frac{P}{\pi D}$; if p is number of poles, and τ is the pole pitch in inches, or distance between adjacent poles measured round the circumference of the rotor, we have the frequency of the generated currents

$$\pi = \frac{P}{60.\pi.D} \times \frac{p}{2} = \frac{P.p}{120.\pi.D} \text{ and pole pitch } \tau = \frac{\pi.D.\,12}{p}, \text{ whence } n = \frac{P}{10\tau}$$

hence we see that the frequency is independent of the diameter of the armature and of the number of poles, and depends merely on the maximum peripheral speed and on the pole pitch. Returning to our example, we have for a frequency of 200,000 cycles, $\frac{P}{10\tau} = 200{,}000$ or $\tau = \frac{P}{2 \times 10^6}$. For ordinary slotted revolving armatures, with the conductors fastened in the slots, the maximum possible value of P may be taken as about 10,000 feet per min. Hence we have $\tau = \frac{10^4}{2 \times 10^6} = \frac{1}{200}$ ins., which can be seen at once to be quite out of the question for practical construction, at least, for anything more than microscopic outputs.

APPENDIX II.

Electric and Magnetic Deflections of Electrons in Valves.

If we have a particle of mass m, carrying a charge e, and moving with a velocity v, and subject it to the action of a magnetic field H at right angles to its direction of motion, the particle will be acted upon by a force $F = Hev$, which is at right angles to both its direction of motion and to the direction of the magnetic field. This will cause it to be deflected from its original direction of motion by an amount $= \frac{1}{2}Ft/m$, where t is the time that the particle is under the action of the force—*i.e.*, $t = 1/v$ where 1 = distance travelled. F = above force.

If now we apply an electrostatic field E the particle will be acted upon by a force $= Ee$, hence since the deflection that this produced depends merely on this force, and other constants, it is evident that the ratio of deflection produced by the magnetic field : deflection produced by electric field $= Hv/E$—that is to say, the greater the velocity of the electrons the greater will be the deflection produced by the magnetic field, as compared with that by the electric field; hence, if we have electrons of low velocity, the electric deflection will be more important, as compared with the magnetic, than it will be in the case of high velocity electrons.

Since, however, the electron is merely a charged particle of mass m and charge e, its velocity will depend on the voltage applied to the valve between the filament and the plate, and will increase with that voltage, since the force on a charged particle, as above, is Ve/d, where V/d is the potential gradient (volts per cm.), therefore it is to be expected that in valves in which the voltage applied between plate and filament is small (as is usually the case) the electric deflection of the electron stream will be the most useful one to employ.

A STUDY OF HETERODYNE AMPLIFICATION BY THE ELECTRON RELAY

Edwin H[oward] Armstrong

A STUDY OF HETERODYNE AMPLIFICATION BY THE ELECTRON RELAY*

By

Edwin H. Armstrong

(Trowbridge Fellow, Hartley Research Laboratory, Department of Electro-Mechanics, Columbia University.)

Part I

The purpose of this paper is to present the results of an experimental investigation of the heterodyne phenomena which occur in the oscillating state of the regenerative electron relay. The questions to be determined were first, the magnitude of the amplification produced by the presence of the local or auxiliary current, and second, the nature of this amplification and the factors which limit its extent.

In self-heterodyne circuits of the regenerative type there are, as the names indicate, two methods of amplification, and these occur simultaneously in the same circuit, each one operating in its own particular way and practically independently of the presence of the other to produce a total amplification proportional to the product of the two. On account of the rather involved nature of the various phenomena, the problem of separating the total amplification into its component parts by direct measurement is not simple and an indirect method is the easiest way out of the difficulty. In the light of our present knowledge concerning self-heterodyne circuits, there is no reason to believe that the magnitude of the heterodyne amplification obtained in these circuits should in any way differ from that obtained in an ordinary circuit with an external heterodyne. Hence by measuring the amplification produced in a simple audion circuit and then by measuring the total amplification produced when the same tube is provided with a regenerative circuit and used as a self-heterodyne, a general idea of the actual and relative magnifications of the two methods may be obtained.

This method of measurement was therefore adopted and the

* Presented before The Institute of Radio Engineers, New York, October 4, 1916.

arrangement of apparatus was made according to the diagram of Figure 1. Referring now to this diagram, M represents the antenna circuit and N the closed circuit of an electron relay receiver which may be made regenerative by the opening of the switch S. The electron relay, which was of the audion type, was used as the detector and a condenser C_1 was included in the grid circuit in the ordinary way. On account of the high vacuum

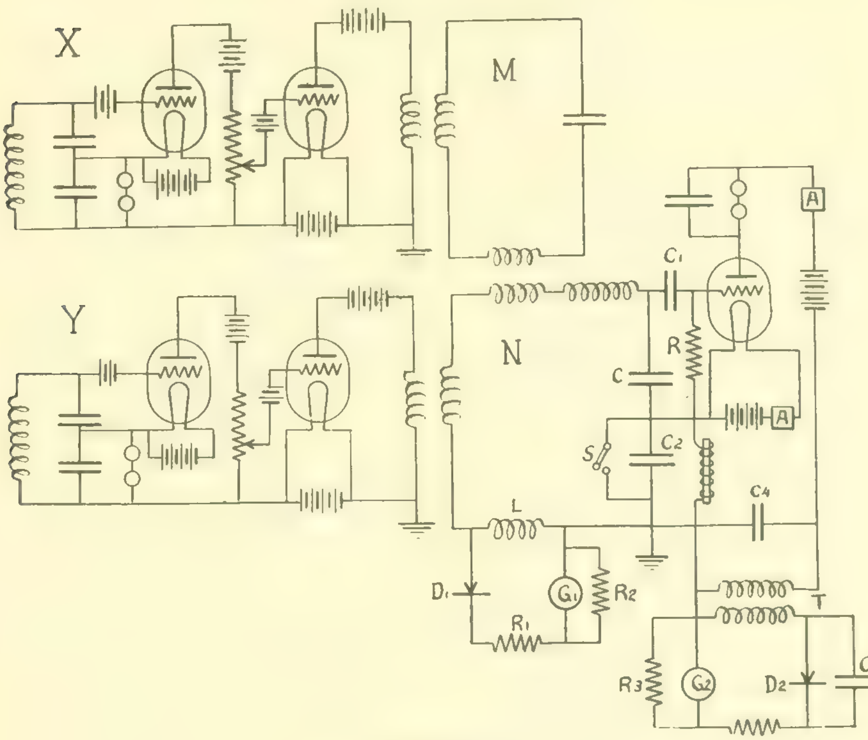


FIGURE 1

of the tube an auxiliary leak was required and a high resistance R was used between the grid and the negative terminal of the filament. The two systems X and Y represent the sources of signaling and local currents respectively. Each system consists of an oscillating electron relay arranged to excite a second relay, the input side of which was connected across a resistance located in the plate circuit of the oscillator. Energy is supplied to the receiver from the plate circuit of the second tube which acts purely as a repeater. This arrangement was adopted in order to prevent the amplification of the signaling current in circuit N by the regenerative action of the circuits of system Y which would occur with a direct coupling between the two. By using

a one way repeater with the input side connected across a resistance in the plate circuit of the oscillator, this danger is avoided. The same arrangement was adopted in system X to prevent the relatively strong local current reacting in any way on the source of the signaling current. The relative amplitudes of the signaling and local radio frequency currents in the closed circuit were measured by means of a silicon rectifier D_1 and a galvanometer G_1. The combination was connected across a small inductance L one end of which was grounded. A shunt resistance R_2 across the galvanometer was used to vary its sensitiveness and a series resistance R_1 was used to compensate for changes in the total resistance due to adjustment of the shunt. The telephone current was measured in the manner described by Dr. Louis Austin* in a recent publication. A telephone transformer T separates the variable components of the plate current from its continuous component and a silicon rectifier D_2 and a galvanometer G_2 located in the secondary are therefore responsive only to changes in the plate current. To separate the audio from the radio frequencies, condensers C_4 and C_5 of 0.01 μf. each were connected across both the primary of the transformer and across the rectifier and as an additional precaution one end of the secondary of the transformer was grounded.

Both the silicon rectifier used for the measurement of the radio frequency and the silicon-arsenic rectifier which was used for the measurement of the audio frequency follow the square law in the lower part of their characteristics; that is, the rectified current is proportional to the square of the alternating current. The reading of the galvanometer G_1 is therefore proportional to the square of the radio frequency current in the circuit N. The reading of the galvanometer G_2 is proportional to the square of the audio frequency component of current in the plate circuit. The alternating current energy available for producing sound is likewise proportional to the square of the current and the reading of the galvanometer G_2 may therefore be taken as a direct measure of telephone signal strength.

In determining the amplification due to the heterodyne method a difficulty is encountered in continuous wave reception due to the fact that when the local current is not present there is no audible signal in the telephones. In order to obtain a tone a chopper must be used in some part of the receiving system. In the present investigation a chopper of the revolving commutator type was used in the antenna circuit and the square

* In the "Proceedings of the Washington Academy of Sciences."

of the variable component of the telephone current taken as a standard of reference on which to base the relative strength of signal produced by the heterodyne.

The first series of measurements were for the purpose of comparing the signal strength obtained with a chopper and that given by the heterodyne when the local current was equal in amplitude to the signaling current. For convenience we may refer to this case as the "equal heterodyne," i. e., "equal other force." The conditions under which the comparison was made were the following: The signaling frequency was set at about 40,000 cycles and the frequency of the local current adjusted to a given beat tone approximately equal to the maximum frequency of interruption produced by the chopper. This was about 600 cycles per second. After a rough adjustment of the tuning and coupling of circuits M and N, the grid condenser C_2 and the auxiliary leak R were adjusted to give maximum response in the telephone. The values of capacity and resistance which gave this result were 0.0001 μf. and 2 megohms respectively. The time constant of the discharge of the grid condenser thru the leak is therefore about 0.0002 seconds. After this adjustment was completed, the local current was cut off and circuits M and N carefully adjusted until a maximum of current was obtained in circuit N as indicated by the maximum deflection of galvanometer G_1. These adjustments were held constant thruout all measurements in which the external heterodyne was used. The comparison was made over a wide range of signal strength and it was found that the equal heterodyne gave a signal which was from four to ten times as loud as that given by the chopper, the greatest advantage being on the weaker signals. The four fold amplification usually attributed to the equal heterodyne with respect to the chopper is fully realized but the ten-fold amplification was rather unexpected. The explanation is, however, a simple one, and will appear in the second part of the paper.

The second series of measurements were for the purpose of comparing the signal strength of the equal heterodyne and that obtained when the local current is increased to its critical value. This case may be referred to as the "optimum heterodyne." The results of these measurements are illustrated by the curve of Figure 2 which shows the relation between the amplification produced by the optimum heterodyne with respect to the equal heterodyne and the amplitude of the radio frequency signaling current. It is evident that the magnification varies over a very

wide range and depends on some inverse power of the signaling current. On the strongest signals the response for the best adjustment of local current was only about one and a half times as great as that of the equal current; whereas, on the weakest signal, the response was increased fifty-five times and the shape of the curve indicated that this would be greatly bettered for still weaker signals. An amplification of several hundred ap-

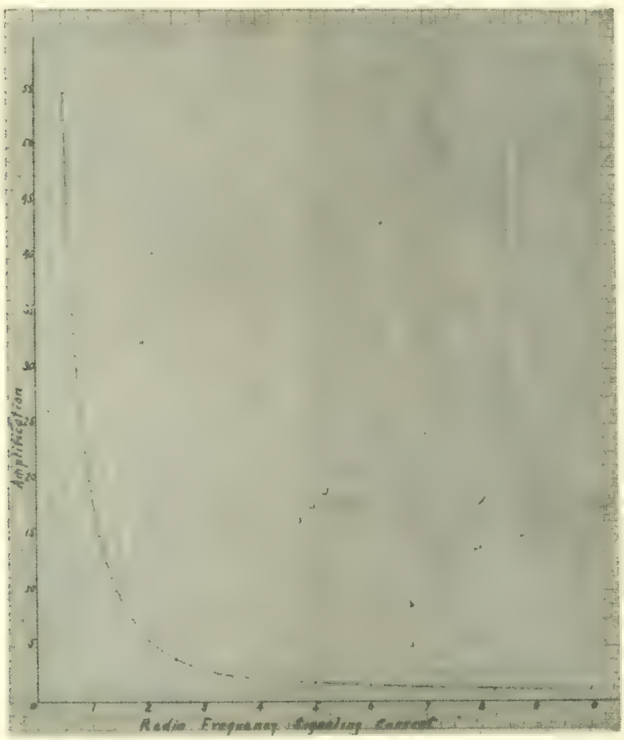


FIGURE 2

pears quite probable. With the apparatus on hand, it was impossible to measure accurately a signal weaker than that on which the fifty-five fold amplification was obtained. The missing part of the curve presents an interesting field for further investigation with more sensitive measuring instruments. An idea of the strength of signal may be gathered from the fact that a shunted telephone test gave an audibility of about one hundred for the weakest signal on the curve. This measurement was made for the equal heterodyne and it is important to note that the method employed was to insert a second pair of telephones in series with the shunted pair and to take the square of

the expression $\frac{Z_T+R_s}{R_s}$ as the audibility. The justification of this procedure will be found in a contribution of L. Israel* which fully covers the present case.

The next series of measurements were for the purpose of determining the relation between the maximum signal strength obtainable with a simple electron relay with separate heterodyne and the signal obtainable when the same relay is supplied with a regenerative circuit and operated as a self-heterodyne. A large number of comparisons were made on a frequency of about 40,000 cycles. The results were extremely irregular due to the very critical nature of the adjustment of the self-heterodyne circuit but there was found to be an average amplification of about fifty times with respect to the signals produced by the external heterodyne. The delicacy of the adjustment may be gathered from the fact that even tho the tuning condenser of circuit N was provided with a handle a foot in length the slightest touch would frequently produce a change of 100 per cent. in the deflection of the galvanometer G_2. In addition to the arrangement of Figure 1, other forms of regenerative circuits were used, including the magnetic coupling and the particular form of static coupling illustrated in Figure 3 which has been termed in some quarters the "ultraudion connection." In spite of the claims by the patentee that it cannot be a regenerative circuit, and his explanation of the method of operation (which, by the way, involves perpetual motion),* this arrangement regenerates very effectively with a good bulb, and gives an amplification about fifty times greater than the simple connection with external heterodyne.

In summing up the total amplification obtained in the regenerative oscillating relay as compared to the signal obtained with the same relay in a simple circuit with a chopper, we find, taking average values, a multiplication of about five times by the equal heterodyne; a further magnification of at least twenty times by the optimum heterodyne, and lastly a fifty fold magnification by the operation of the regenerative circuit making a total of approximately 5,000. This figure has been checked by direct measurement and on weak signals even greater amplifications have been obtained.

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* "Proceedings of The Institute of Radio Engineers," volume 3, 1915, page 183. It should be noted, however, that as a high vacuum tube was used, changes in the resistance of the plate potential by adjustment of the shunt will not affect its sensitiveness. The sole object of the extra pair of telephones was to maintain constant the impedance of the plate circuit for the audio frequency current.

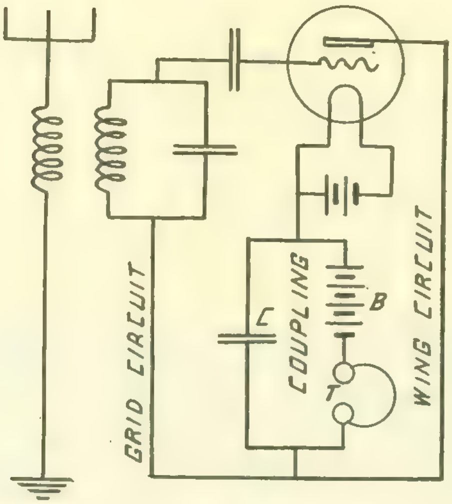


FIGURE 3

PART II.

THE NATURE OF THE HETERODYNE PHENOMENA

Several writers have treated the heterodyne phenomena mathematically,* but on account of various difficulties which arise, none of the treatments have been rigorous. When the special case of the current rectifier type has been considered it has been largely on a basis of physical reasoning. Without entering into details of the operations employed in getting at results, we may consider the conclusions arrived at by the various writers. They may be divided into two general classes, one of which supports the view that the amplification which may be obtained is, theoretically, unlimited, the practical limit being determined by the disturbances produced in the receiving system by the local frequency and the current carrying capacity of the detector. The second theory, which is that due to

* PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS," volume 4, 1916, page 266. Discussion on paper by Dr. L. W. Austin entitled "Experiments at U. S. Naval Radio Station, Darien." de Forest states "the circuit cannot be regenerative," and that the manner of operation is such that "a sudden change of potential impressed on the plate produces in turn a change in the potential impressed on the grid of such a character as to produce, in its turn, an opposite change of value of potential on the plate, etc. Thus the to-and-fro action is reciprocal and self-sustaining, etc." And all this self-sustaining to-and-fro action between grid and plate goes on (according to de Forest) *without any energy being supplied to the system!*

Also Hogan, "Proc. I. R. E.," July, 1913.
Cohen, "Proc. I. R. E.," July, 1913; June, 1915.
Liebowitz, "Proc. I. R. E.," June, 1915.
Latour, "Elect. World," April 24, 1915.

Liebowitz, states that the maximum true amplification due to the heterodyne is four; that this is obtained when the local current is equal in amplitude to the signaling current, and that any further increase in response which may be obtained by an increase in the local current is due to an improvement in the efficiency of the receiving apparatus and is governed by the usual limit in such cases, namely 100 per cent.

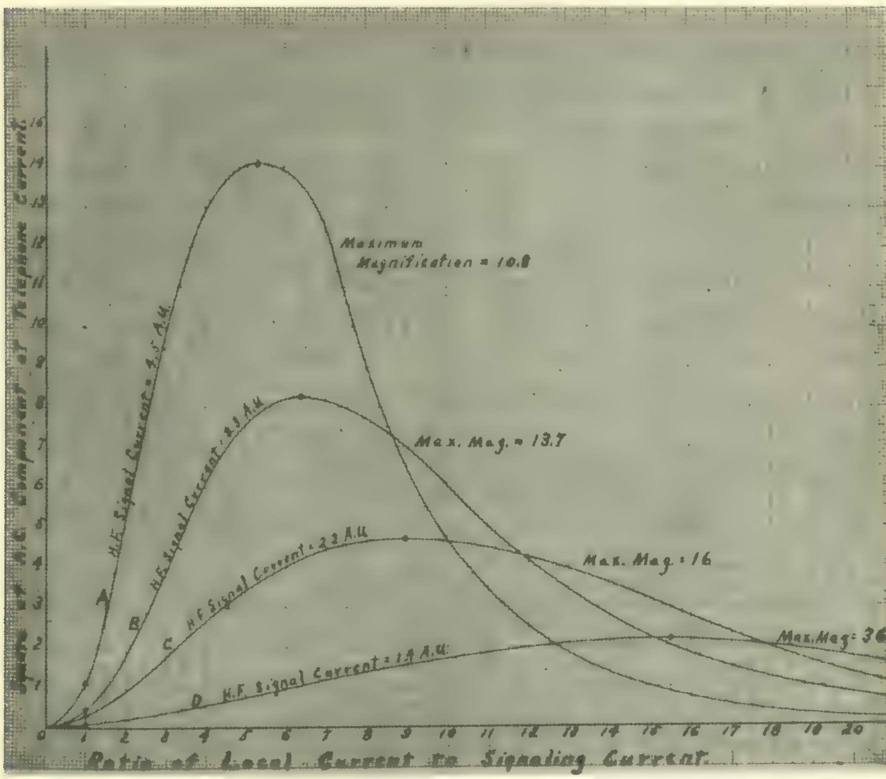


FIGURE 4

From an experimental standpoint, the key to the true nature of the phenomena would appear to lie in what may be termed the "heterodyne characteristic"; that is, the relation between telephone signal strength and the ratio of local to signaling current. A number of these characteristics for various values of signaling current were therefore obtained and the results are shown graphically in Figure 4. The ordinates of these curves represent the available energy in the telephones for producing a tone and the abscissa are in terms of the ratio of local to signaling current. It will be observed for all four values of signaling current that an increase in the ratio of the local to the signal-

ing current beyond the one-to-one point produces a very rapid increase in telephone signal strength which continues up to a certain maximum value. The maximum is maintained for a limited range and then the curves fall off and gradually approach zero value. This is the typical heterodyne characteristic for the current rectifier and the explanation of the phenomena attending the rise and fall of these curves should definitely determine the nature of the amplification.

The rapid rise in the curve as the local current is increased beyond the one-to-one point will be found in the shape of the rectifying or valve characteristic of the relay. In relays of the audion type, this characteristic is the relation between the gird voltage with respect to the filament and the grid-to-filament current. The curve of Figure 5 shows this relation for the relay which was used in obtaining the curves of Figure 4. The grid

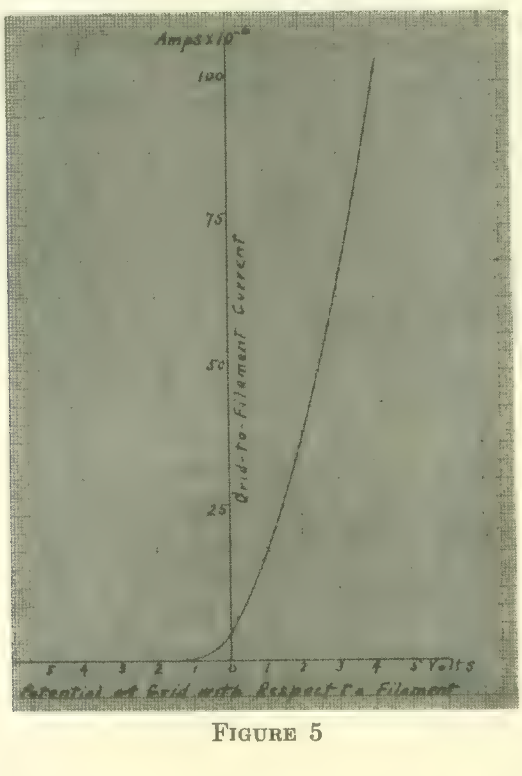


FIGURE 5

current is the actual conduction current flowing between grid and filament, and it is on the amplitude of this current that the value of the cumulative charge in the grid condenser depends. The curve may be divided into two parts, the upper section of which is practically a straight line and the lower section of which

is curved in such a manner that the ordinate is proportional, approximately, to the square of the abscissa. On account of this curvature, a difference exists between the conditions of operation of the equal and optimum heterodyne. A graphical representation of these conditions is given by Figure 6. In case (A), which shows the equal heterodyne a local voltage of amplitude V is continuously applied and maintains a continuous

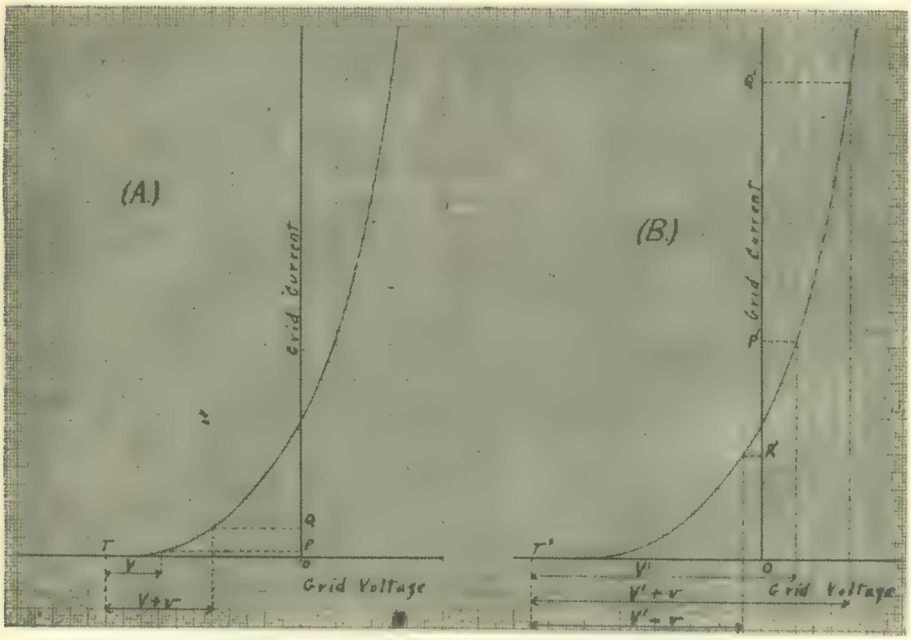


FIGURE 6

negative charge on the grid of some potential T. The value of the steady charging current is proportional to $O\,P$. When the signaling voltage v is superposed, we get, for the additive state a total voltage of $(V+v)$ and the charging current becomes proportional to OQ. For the opposing state the voltage $(V-v)$ is equal to zero and the charging current is consequently equal to zero. The total variation of the grid condenser charging current, and hence the variation in the average value in the average value of the grid potential, is between $O\,Q$ and zero. The conditions of the optimum heterodyne are those illustrated by (B). A local E. M. F. of amplitude V' many times greater than the signaling voltage v continuously maintains the average value of the grid potential at some negative value T'. The steady value of charging current corresponding to V' is proportional

to $O' P'$. When the signaling E. M. F. is superposed for the voltage (V^1+v) the charging current is given by $O' Q'$ and for $(V'-v)$ by $O' R'$. The total variation in charging current is therefore proportional to $(O' Q'-O' R')$ or to $R' Q'$ which is obviously very much greater than the variation $O Q$ in the charging current for the equal heterodyne.

It must be here stated that the foregoing analysis must not be taken too literally as to quantitative results. Tendencies only are represented and these are limited by certain factors which will now be taken into account. The most obvious limit to an ever-increasing amplification by increase of the local current even if the valve characteristic followed the square law thruout is the counter E. M. F. of the grid condenser. The variation of the average value of the potential difference across this condenser can clearly never exceed the variation in amplitude of the beat voltage across the tuning condenser to which the relay is connected. When the efficiency of rectification is poor, as it is on the lower part of the characteristic, the counter E. M. F. of the grid condenser is negligible in comparison with the resistance reaction of the value. As the efficiency of rectification is improved by means of the local frequency, the back E. M. F. of the condenser becomes the dominating reaction of the circuit and definitely limits the variation of the charging current. The phenomena are almost identical with the action of the electrostatic telephone and coincides exactly with the theory of Liebowitz. In the case of the electrostatic telephone, the increase in the efficiency as the local current is increased produces a greater amplitude of vibration of the diafram. This in turn produces an increase in the counter E. M. F. of the telephone which reduces the amplitude of the signaling current and consequently the variation in amplitude of the beat current. In the vacuum valve, the same increase in efficiency is obtained until the resulting increase in the counter E. M. F. of the part of the apparatus on which the work is being done (in this case, the grid condenser), definitely limits further amplification.

The fall of the curves of Figure 4 are apparently due to the overloading of the tube by the local current. The steady value of the grid condenser charge maintained by the local current gradually cuts down the plate current as the ratio of local to signaling current increases. This interferes with the relay action of the tube; and finally, when the plate current is reduced to zero, renders it entirely inoperative. This form of overloading may be compensated for in the manner shown in Figure 7 by

means of an auxiliary battery in the grid circuit which makes it possible to maintain the plate current at its normal value. The effect of this auxiliary voltage in compensating for the grid charge is shown by the two curves of Figure 8. Curve A was taken with the arrangement of Figure 7 while curve B was taken in the same manner as the curves of Figure 4. The curves are self explanatory in this respect. It will be noted, however,

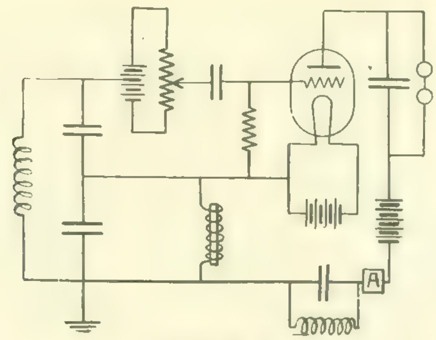


FIGURE 7

that curve A, even when the effect of overloading of grid condenser is removed, eventually shows a tendency to fall off. This is undoubtedly due to another form of overloading, caused by the radio frequency variations of the grid potential overrunning the straight part of the grid potential-plate current characteristic and thereby interfering with the audio frequency repeating action. It is difficult to determine from the heterodyne characteristics of Figure 4 whether the peaks of the curves indicate a maximum of efficiency of rectification or the beginning of the overloading of the tube. The shape of the curves indicate the latter especially on the stronger signals, but it is in any case immaterial whether the limitation of apparatus or method predominates in present-day practice. It is entirely clear that outside of the four-fold amplification of the equal heterodyne, any further amplification by increase in the local current is purely a question of improvement in efficiency.

One of the remarkable features of the curves of Figure 4 is the very rapid increase in the telephone signal strength for a relatively small change in the local current. In the case of curve A, the change from the equal heterodyne to the two-to-one ratio gave a response in the telephones four times as great as for the one-to-one ratio. The reason for this will be found in the energy relations in the tube with respect to the radio

frequency current. The rectifying characteristic shows that the charging current of the grid condenser and hence the grid potential is proportional to the square of the radio frequency current. The useful telephone current is proportional to the change in potential of the grid and hence to the square of the radio frequency current. The energy in the telephones available for producing a tone is therefore proportional to the fourth power

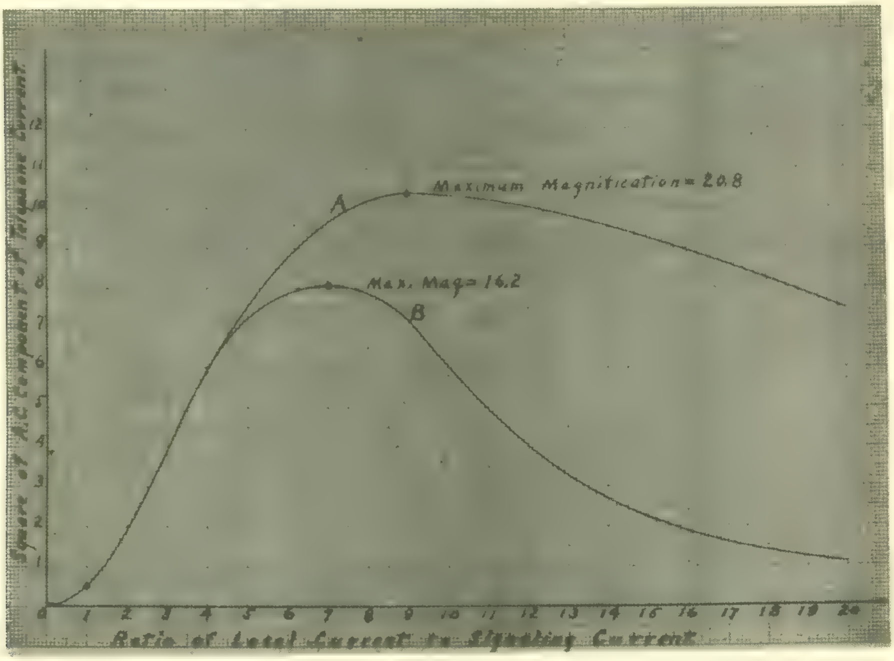


FIGURE 8

of the radio frequency current. In the case of the equal heterodyne, the variation in amplitude, assuming unity value of signaling current, is between 2 and 0, and for the 2:1 ratio it is between 3 and 1. The relative telephone currents are therefore proportional to 2^2 and (3^2-1^2) or to 4 and 8. The relative telephone signals are according to the square of these values or in the ratio of 1:4. This corresponds almost exactly with the experimental result.

The shape of the valve characteristic also explains the interesting fact discovered by Dr. Austin,* that the plate current is proportional to the second power of the radio frequency current in the non-oscillating state but to the first power in the oscillating state. In the non-oscillating state, the rectification takes place

* "Bulletin Bureau of Standards," **11**, 77, Reprint 226, 1914.

on the lower part of the curve where the square law holds (with reference to zero current). In the oscillating state the operation takes place on an upper part of the curve which, for small changes of potential is practically a straight line.

It is evident from this that a regenerative receiver in the oscillating state delivers to the telephones an amount of energy which is proportional to the energy of the radio frequency current in the antenna. The relative amplitude of stray to signaling current in the telephones is therefore independent of the size of the antenna, and barring physiological effects and the possibility of overloading the tube, the readableness of signals should also be independent of antenna size. In ordinary practice this seems to be the case.

In the non-oscillating state the first power proportionality between antenna and telephone energies is maintained only for strong signals. For weak signals or even moderately strong signals the telephone current is proportional to the square of the antenna current. This means that in the working range the telephone energy will fall off very rapidly with a decrease in antenna energy with the result that the smaller the antenna the greater the ratio of the intensities of strays to signals in the telephones. Hence it follows that the larger the antenna the more readable the signals.

The relative effect of antenna size on readability of signals is well illustrated by experiences in the reception of the continuous waves of Nauen and Eilvese and the damped waves of Glace Bay at stations in the vicinity of New York. It is a well known fact that on a small antenna the German stations give more readable signals thru strays than the Glace Bay station. On a large antenna the conditions are reversed and the Glace Bay signals are by far the best.

In conclusion, the writer wishes to state that this paper does not pretend to be in any way an exhaustive treatment of the heterodyne phenomena. Only the outstanding features have been considered, but it is believed that it has been established from an experimental and physical basis that there is a very definite limit to the amplification which can be produced by the heterodyne action. The analysis of the mechanism of the amplification occurring in the electron relay receiver supports in every respect the conclusions of Liebowitz.

SUMMARY; The amplifying action of the regenerative oscillating electron relay is carefully studied. It is found, by separation of the various effects, that there exist three distinct types of amplification. The first, or ***equal heterodyne*** type, occurs when the local oscillating current is equal to the signaling current. The second, or ***optimum heterodyne*** type, occurs when the local oscillating current is increased to the critical value for maximum response. The third, or ***regenerative*** type, results from the amplifying action of the relay and its associated circuits. The roughly approximate numerical values of the three types are five-, twenty-, and fifty-fold, making a total amplification of five thousand times or more.

The mechanism of these phenomena is considered in detail with especial reference to the limitations of each process.

DISCUSSION

C. J. De Groot (by letter): Mr. Armstrong's paper has made quite clear numerous matters of interest. He has shown how many functions the vacuum amplifier may have independently and simultaneously when used as a beat receiving device of the internal heterodyne type. He has shown further how astonishingly large may be the amplification of signal thus produced by these simultaneous functions as compared to plain reception with a detector valve or tikker. The separations of these different functions and a determination of the amount which each contributes toward the total amplification including the values which have been checked by direct measurement, have indeed been thoroly planned and well executed.

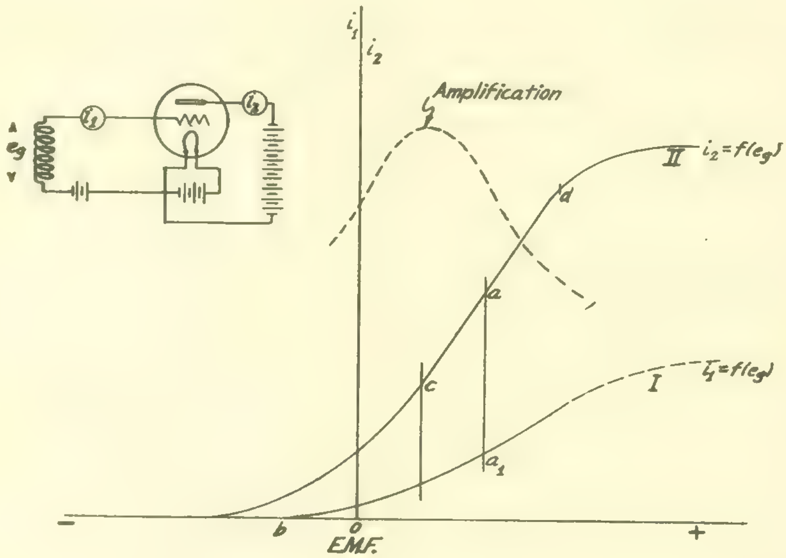
There is one point for which I would submit an explanation of my own for the consideration of the speaker. This is the limitation of amplification which is found to occur for strong local currents.

Instead of showing, as did Mr. Armstrong, the filament-to-grid characteristic, should we not rather show simultaneously two characteristics, namely the following: the filament-to-grid characteristic and the filament-to-plate characteristic. Let us suppose that the E.M.F. of both the filament heating battery and the plate circuit battery to be constant, and give these the values V_1 and V_2. Let us alter only the E.M.F. between the filament and the grid and plot the grid and plate currents as functions of this applied E.M.F. Then the two characteristics have the general shape shown in the Figure. The function of the local current is firstly to produce beats (and there is no advantage in this regard in going beyond the *equal* heterodyne), and secondly to work at a local current which brings us to the most favorable part of the characteristic for amplification.

If then we take into consideration only curve II of the Figure, we reach the conclusion that we should supply the amplifier with a local current corresponding to the point a of the curve, since for this part of the curve $\frac{d\,i_2}{d\,e_{gr}}$ is a maximum, and therefore the current change (or amplified signal) is greatest for a given change in E.M.F. (or incoming signal).

On the other hand, we see from curve II that working at this point implies a certain current i_1 in the grid-to-filament circuit, and this current involves a *loss of energy* in its passage thru the resistance of the circuit. Thus part of the input will

be absorbed. Since we desire a maximum amplification we must search not only for the condition where the output is a maximum (i.e., the condition corresponding to point a) but for the condition whereby this large output is attained by the smallest possible input and the condition, therefore, for which output divided by input is a maximum. Now, since the output



is a maximum near a and the input a maximum near b, it follows that the maximum amplification will be secured for a point somewhere between a and b, say at c. This condition will be reached whenever the tube is so adjusted that it works at what has been called the "optimum heterodyne." For more powerful locally generated oscillations we have to work at those points of the characteristic curve which require a considerable expenditure of input energy in the grid-to-filament circuit, and the efficiency of the device (output divided by input) is diminished. In consequence, we explain the results shown in Mr. Armstrong's curves in Figures 4 and 8 as follows: As we increase the strength of the local oscillations past the point of equal heterodyne, we cannot improve the beat production but the amplification increases because the larger local oscillating circuit (when considered in conjunction with the tube characteristics) brings us to the point a where $\frac{d\,i_2}{d\,e_{gr}}$ is a maximum. A second reason is that $\frac{d\,i_2}{d\,e_{gr}}$ increases to the point a after which it falls again, and

there should result a decrease of amplification beyond the point a. This decrease is emphasized by the fact (seen from curve I) that the larger the local oscillating current, the larger $\frac{d i_1}{d e_{gr}}$ that is, the greater the waste of input energy, $(d i_1)^2 r$, for the same incoming signal, $d e_{gr}$. A third reason for the decrease of amplification may be the fact, stated by Mr. Armstrong himself, that even working at the most suitable point of the curve (c), a strong signal may exceed the limitations of the characteristic curve II, thus giving a $\frac{\Delta i_2}{\Delta e_{gr}}$ smaller than the $\frac{d i_2}{d e_{gr}}$ for infinitesimal signals at c.

We should keep in mind that, for reasons of convenience, we have used static characteristics (as also did Mr. Armstrong) tho, strictly speaking, dynamic characteristics should be used.

The method of shifting the maximum amplification to points of higher local oscillating current as shown in Figure 8 of the paper is readily explained by the considerations here given. The steady E.M.F. applied in the grid-to-filament circuit, which is there recommended, displaces curve I horizontally relative to curve II, so that the point b of curve I is brought below point a of curve II. We can therefore work the system nearer the point a which is the point of maximum amplification. In this case the amplification should be quite independent of the signal strength as long as the signals added to the local current do not run beyond the portion cd of the curve II. For stronger signals a decrease of amplification will occur because of the general shape of curve II.

Edwin H. Armstrong (by letter): Dr. de Groot has raised a very interesting point concerning the factors which limit the amplification obtainable by the optimum heterodyne. It is in line with the explanation of Liebowitz when the electrostatic telephone is the detecting agency; viz.: that the increase in efficiency of the detecting apparatus as the auxiliary current is increased creates a counter E.M.F. or an increase in the effective resistance of the circuit to which it is connected. I expected to find that this increase in effective resistance of the main circuit would be the most predominant factor in limiting the amplification obtainable by the optimum heterodyne and was exceedingly astonished to find that the effect was a relatively unimportant one.

This was readily determined with the arrangement of Figure 1

and the experiment was made in the following way. With condenser C_2 short-circuited to eliminate the regenerative feature and with a predetermined value of signaling current, the equal and optimum heterodyne telephone currents were measured. A resistance of 5,000 ohms was then introduced into circuit N between the loading coil of the circuit and the coupling coil connecting it with the antenna. The signaling current was restored to its initial value by increasing the power of the system X, and the equal and optimum heterodyne currents again measured. Little difference was observed in the amplification obtainable with the low resistance circuit, which measured about 300 ohms and the high resistance circuit which was approximately 5,300 ohms, and this, in itself, is conclusive evidence that the effective limitation is not due to an increased resistance in the main circuit. Further investigation developed that the predominant limiting factors lie along those lines presented in the paper.

The result was so unexpected that some further experiments were made with a view of determining, if possible, the reason for the absence of the phenomena so clearly brought out by Dr. de Groot. While lack of opportunity prevented a complete investigation, the reason appears to be in the fact that the relay, which was of the same structure as the standard de Forest audion, did not fit efficiently into the circuit to which it was connected. The relay contributed only about 15 per cent. of the total effective resistance of the circuit, and it was hardly possible to improve this very much and still keep the capacity across which the relay was connected at a reasonable value. About 0.0004 microfarad was normally used, which is, perhaps, as low as good commercial practice permits. As a consequence of this low efficiency, other factors exert their influence upon the maximum amplification before the increase in efficiency of the detector produces any noticeable effect. The practical significance of this is that the tube used was ill adapted to fit into ordinary commercial circuits, and that a larger tube could be more efficiently used. Aside from the relative magnitude of the effect indicated by Dr. de Groot, I am entirely in accord with the points he has so clearly presented.

Carl Ort (by letter): The paper under consideration constitutes a very thoro investigation of the so-called "heterodyne" receivers, and shows that this system, when used in conjunction with a rectifying detector, operates on an entirely different

principle from that explained by Messrs. J. L. Hogan, Jr., and L. Cohen. Professor Fessenden first used a sustained wave oscillator for the purpose of producing beat tones in the receiver. As far as the patent literature or other publications indicate, he used an electromagnetic receiver; and later, when it was shown by Mr. Rieger and myself that the electrostatic receiver could be made very sensitive by proper construction (see articles on condenser receivers in "Elektrotechische Zeitschrift," 1909, page 655 and "Archiv für Elektrotechnik," 1, 1912 page 192) he replaced the electromagnetic receiver by an electrostatic one with much success. Mr. Lee and Mr. Hogan later replaced the electrostatic receiver by a crystal detector (See the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, 1, July, 1913, and U. S. patent 1,141,717) with the result that much higher sensitiveness was obtained than with any previous receiving system. Messrs. Hogan and Cohen explained the large amplification by assuming that the process amplifies the received antenna energy, and that the crystal detector rectifies merely this amplified energy. But it was shown by Mr. B. Liebowitz that the maximum amplification of this combination should be 4. (See the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, 1915, page 185). Mr. Armstrong's experiments have shed new light on these phenomena and have indicated that the amplification obtained with a rectifying detector depends on the energy of the local oscillations which are applied to the detector, and that while the energy received is not magnified at all, the sensitiveness of the detector is increased. This increase is independent of the frequency of oscillation of the local source.

It may be of interest to describe some experiments which I began in December, 1912, in a small town in Austria. At the time I was carrying on radiophone experiments, using a small Poulsen arc as a transmitting source. One day it happened that I received not only the speech from my arc station but also the noon time signals of the German Post Office station at Norddeich. This latter station was distant from my home about 380 miles (600 km.), the entire distance being over mountainous land. Two things struck me at once. To begin with, I was impressed by the great distance over which I was receiving with my small antenna, this being only about 30 feet (9 m.) high and about 90 feet (27 m.) long. Furthermore, I noticed that the tone of the signals received with a crystal detector was no longer musical but resembled that obtained when a tikker was used. (The Norddeich station sends out noon signals

with a 10 K. W. Telefunken quenched spark transmitter, with a 1,000 cycle note). Later I investigated the latter phenomenon, applying sustained oscillations directly to the detector, and found that the amplification was due to the increase of sensitiveness of the detector. Every integrating (rectifying) detector showed this characteristic. I found that the amplification could be obtained with any frequency not audible to the human ear. The limit of amplification was determined by the maximum impressed voltage of sustained radio frequency at which the detector burned out. I was able to obtain amplifications of about 20-fold. In order to explain this effect, I applied the polarisation theory given for the condenser receiver (as cited above), stating that the amplification was proportional to $(i_1+i_2)^2=i_1^2+2\,i_1\,i_2+i_2^2$ where i_1 is the received current and i_2 the local current produced in the detector circuit by the local source of sustained oscillations. I called this phenomenon the "polarisation of integrating detectors" because every detector with a rectifying characteristic can be polarised in this way by applying a polarisation radio frequency sustained voltage at its terminals. For this reason the latter term may be applied to this method in place of the "equal and optimum heterodyne" designation used by Mr. Armstrong. From the very beginning of my experiments I considered the production of beats by this method when used for receiving sustained oscillations as a natural consequence. However, it is not at all necessary to produce beats for receiving sustained oscillations when this method is used with equal frequencies and an Einthoven thread galvanometer is used as an indicating instrument. The same amplifying effect is then obtained, and I do not see any reason why it should be called a "heterodyne" method in this case. The same amplifying effect can be used at equal frequency for radio telephony.

It is unnecessary for me to explain the great advantages of the "polarised integrating method" because they are very well known to the readers of the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS. The purpose of this communication is merely to indicate my part in the development of this method. Mr. Armstrong's paper and Mr. Liebowitz's conclusions verify the conclusions which I drew from my observations four years ago, but could not publish for patent reasons and because of war conditions abroad.

Edwin H. Armstrong (by letter): As Mr. Ort points out, the function of the auxiliary circuit, when carried beyond the

"equality of current" stage, is a polarizing one, and in the present case the phenomenon referred to as the optimum heterodyne is that of a polarised integrating detector. The terms "equal and optimum heterodyne" were used purely for purposes of convenience of reference, and if more suitable terms be suggested, we should, of course, employ them. In view of Mr. Ort's proposals, I would suggest that the matter be taken under consideration by the Committee on Standardization of THE INSTITUTE OF RADIO ENGINEERS.

Lee de Forest (by letter): I doubt if the simplicity of Mr. Armstrong's explanations of audion phenomena is satisfying to those who have extensively experimented with the audion.

For example, readers of his previous paper on the audion might well be satisfied with his theory of the rectification phenomena which obviously *must* there occur—until there transpires the simple experiment of making all three audion electrodes incandescent! The fact that the audion action is thereby unaffected, while the Edison hot-to-cold rectification is made impossible is yet to be explained by the advocates of the Fleming valve theory.

Similarly, in criticism of the too simple explanations advanced in the present paper, an easy experiment with the incandescent grid shows that the ultraudion amplifying processes are unaffected. And it is well known that with the proper audion and "wing-and-grid" oscillating circuits, a grid-charging or "*C*" battery is unnecessary to obtain a maximum efficiency detector of sustained oscillations.

These are experimental facts and not theory, and Mr. Armstrong must search more deeply before the ultimate explanation of audion phenomena is revealed.

This writer has sophistically misinterpreted my discussion on Dr. Austin's recent paper (PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 4, number 3, page 266). There is nothing therein contained to lead any one to suppose that I am an advocate of the unconstitutionality of the law of the conservation of energy.

Edwin H. Armstrong (by letter): In reference to Dr. de Forest's discussion, I feel that he must have failed in some way to understand the present paper because his discussion clearly seems to apply not to the present paper but to some of the more faundamental and elementary matters which were published by me several years ago. However, in view of the part which the

fundamental theory played in the Fleming valve litigation of recent date, I take the present opportunity of laying before the membership of the INSTITUTE the details of what has been to me a most interesting controversy.

During the course of the litigation in question (Marconi vs. de Forest), plaintiffs introduced as evidence showing infringement an article on the operation of the audion which I published in the "Electrical World" of December 12, 1914. This article showed clearly, with oscillographic proof, the manner of the filament-to-grid valve action as well as other methods of use for producing rectification. A most determined effort was made by the de Forest experts and counsel to invalidate the theory. About fifty pages of testimony were introduced showing experiments designed to prove that when signals were received, the charge on the grid became *positive* and hence that any theory of rectification based on the grid becoming negative was incorrect. It was stated that these experiments had been repeated and confirmed by the United States Bureau of Standards.

The manner in which these tests had been made was briefly as follows. A voltmeter consisting of a sensitive galvanometer in series with a resistance of the order of a megohm was connected between the grid and filament of an audion which was arranged in the usual way with a tuned circuit and stopping condenser. Coupled with this tuned circuit was a second tuned circuit driven by a buzzer exciter. It was stated by the de Forest experts that when the circuits were excited and radio frequencies applied to the grid the deflection of the voltmeter showed a positive charge on the grid. I repeated these experiments with buzzer excitation and under certain conditions found that the voltmeter would indicate a positive charge on the grid, but that when the receiver was connected to an antenna and outside signals were received, the grid invariably became *negative.* Investigation showed immediately that a rather curious effect produced on the tube by the high voltage across the break of the buzzer was responsible for the apparent indication of a positive charge. I was able to testify in court to these interesting facts with the result that counsel for the de Forest Company were forced to withdraw all fifty pages of testimony and *admit on the record that the grid became negatively charged.* After this collapse of the positively charged grid theory, the defense built up another based on a "sensitive medium" ionized to an "optimum value" and constructed an audion with an incandescent grid to prove that rectification was not essential to the operation of the

device as a detector. The manner of operation of this device will appear from the oscillograms of Figures 11 and 12 of the "Electrical World" article from which it will be obvious that the rectifying action of the tube will continue irrespective of the temperature of the grid.

In upholding the validity of the Fleming patent and finding that the use of the audion as a detector was an infringement thereof, the Court stated that the "Electrical World" article might be considered as read into his opinion. In view of this fact and in view of the fact that the theory has withstood intact the test of publication and discussion in the PROCEEDINGS, the controversy must now be considered as settled, and I must refuse to enter into any further discussion of these elementary matters.

UNITED STATES RADIO DEVELOPMENT

Robert H. Marriott

UNITED STATES RADIO DEVELOPMENT*

By

ROBERT H. MARRIOTT, B.Sc.

(PAST PRESIDENT OF THE INSTITUTE OF RADIO ENGINEERS, EXPERT RADIO AIDE, U. S. N.)

Before taking up the radio development of the United States as a whole, some of the more notable instances of Pacific Coast development will be cited. The Pacific Coast is particularly noteworthy for early construction *combined* with *lasting* construction.

The first *permanent* COMMERCIAL PUBLIC SERVICE radio station in the United States, using U. S. built apparatus, was constructed at Avalon, Santa Catalina Island, California in the spring of 1902.

At the same time this station became the first *permanent* station in the United States to adopt exclusively the telephone method of reception.

The first *permanent* radio trans-oceanic service from United States soil was established between California, near San Francisco, and Honolulu in 1912. Also these were the first stations permanently to use the constant amplitude type of transmitters.

The first PERMANENT, COMMERCIAL, OVERLAND, PUBLIC SERVICE, RADIO STATIONS using CONSTANT AMPLITUDE transmitters in the United States were established by the Federal Telegraph Company, between San Francisco and Los Angeles in 1911.

At an early date the Army constructed stations at Nome and St. Michaels, which, from 1904 on, became known for the comparative reliability with which they rendered radio service between these points.

We may now take up radio development in the United States as a whole. In numerical results given in this paper, only

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* A paper delivered before a joint meeting of the American Institute of Electrical Engineers and The Institute of Radio Engineers at the Panama Pacific Convention, San Francisco, September 17, 1915. This paper is based on Government records as found by the writer, and on the writer's notes and recollection. The records and notes are too voluminous to include in a paper of this kind; for example, about 3,000 sheets were used to classify and enumerate the radio transmitters.

Government stations and stations established for commercial purposes have been included because it was found that the number of experimental stations, their date of use and the apparatus used, was indefinite, extremely complicated, and required lengthy explanation.

Considering Chart 1 marked United States "Wireless" Telegraph Development (transmitters):

This chart shows the total number of transmitters and the total number of each class of transmitters for each year from 1899 to 1915, together with manufacturers of these transmitters and operating organizations.

Plain Antenna Transmitters (P. A. Class) shown in black includes the type of transmitters wherein the antenna was connected to one side and the ground to the other side of the spark gap of an induction coil.

Tuned Coupled Circuit Transmitters (C. T. Class) shown in heavy diagonal lines, includes, for example, the transmitters where an antenna in series with an inductance was tuned to the same frequency, and inductively coupled to a circuit containing a plain spark gap in series with an inductance and leyden jars. United Wireless Telegraph Company transmitters were commonly of this type.

Impulse Excitation Transmitters (I. E. Class) shown in lighter diagonal lines, includes, for example, the quenched gap type of apparatus. The Telefunken Company transmitters were commonly of this type.

Constant Amplitude Transmitters (C. A. Class) shown in white, includes transmitters which produce constant amplitude alternating current in the antenna. Federal Telegraph Company arc transmitters, and radio frequency alternators are included under this class.

With the exception of the number of stations equipped with the different classes of transmitters and the names of Companies, the points in this chart are contained in a general way in Chart 2 and its discussion.

Curve *R* at the top is intended to indicate the approximate maximum distances used for public or government service each year from 1899 to 1915 referred to the numerals at the left reading from 0 to 4,000 and marked "Range in Miles." (1 mile = 1.6 km.)

Curves *T*, *S*, *L*, *V*, and *G* are intended to indicate the number of stations each year from 1899 to 1915 referred to the

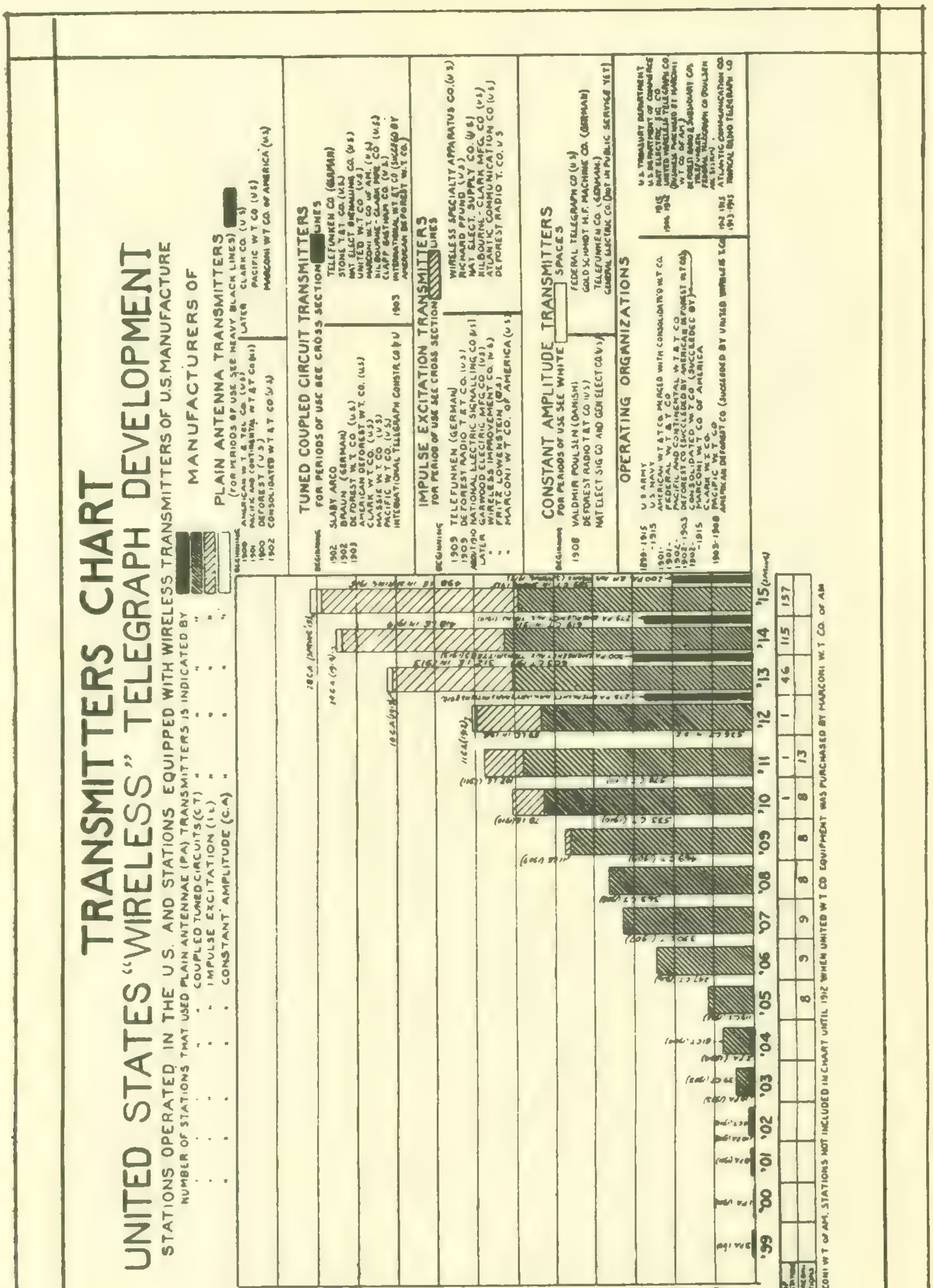
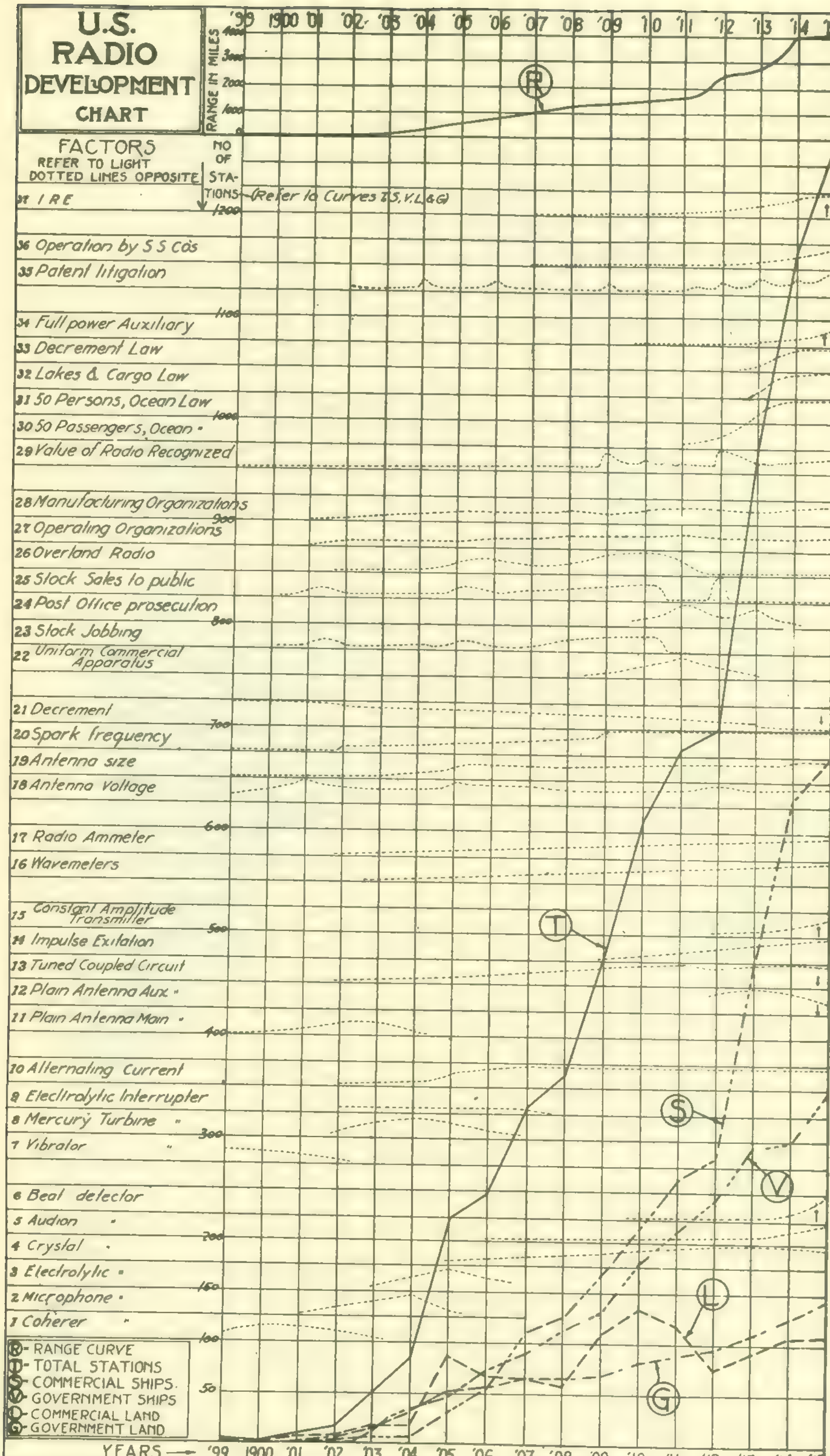

TRANSMITTERS CHART
UNITED STATES "WIRELESS" TELEGRAPH DEVELOPMENT
STATIONS OPERATED IN THE U.S. AND STATIONS EQUIPPED WITH WIRELESS TRANSMITTERS OF U.S. MANUFACTURE
MANUFACTURERS OF
PLAIN ANTENNA TRANSMITTERS
TUNED COUPLED CIRCUIT TRANSMITTERS
IMPULSE EXCITATION TRANSMITTERS
CONSTANT AMPLITUDE TRANSMITTERS
OPERATING ORGANIZATIONS
NUMBER OF STATIONS

CHART 1



UNITED STATES RADIO DEVELOPMENT CHART 2

Numerals at the top and bottom of this chart indicate years

numerals at the left reading from 0 to 1,200 and under the heading "Number of Stations."

These curves, particularly in latter years, lag somewhat because it frequently happened that the existence of stations was not recorded or was unknown to the writer until the following calendar year. Data for 1915 was brought up to about June 1.

CURVE *T*—Total number of radio stations in the United States. (Government and commercial)

CURVE *S*—Number of commercial ship stations

CURVE *L*— " " " land "

CURVE *V*— " " Government ship "

CURVE *G*— " " " land "

Under the heading of "Factors" at the left on chart 2 is a list of subjects, numbered on the extreme left. The lighter dotted curves extending across the chart in the single narrow spaces opposite these subjects are intended to indicate approximately the rising, falling, peaks, and depression in the history of these subjects or factors.

1. COHERER. This form of detector was used in the Navy stations in 1899. Apparently coherers of English Marconi Company and Navy make were used. Owing to its insensitiveness and uncertainty of action, the coherer was almost entirely discarded in the United States by 1903 as, indicated by the light dotted line opposite "Coherer" on the Chart. Changing from the coherer was one of the greatest steps, not only by virtue of increased sensitiveness and reliability, but by leading to detectors more capable of utilizing long wave trains thereby making it easier to construct more powerful transmitters.

2. MICROPHONE. This is intended to include the class of detectors which superseded and took the place of the coherer. As a rule, they consisted of a contact between steel and carbon, or steel and aluminum; however, the detectors as used at Avalon and Whites Point, California, consisted of the contact between steel and an oxide of iron (and thus may have had more of the qualities of the crystal detectors). The microphone was abandoned largely because of its lack of stability.

The arrival of the microphone marks the arrival of the lasting telephone method of reception, a revolutionary and comparatively large step in radio advancement.

3. Electrolytic. This detector succeeded, and took the place of the microphone. At its best it was very sensitive but atmospherics destroyed its extreme sensitiveness and the acid used in it damaged other things. A court decision tending to give Mr. Fessenden and his associates a patent monopoly on this form of detector apparently hastened its disapproval and disappearance.

4. Crystal. This detector succeeded and took the place of the electrolytic partly because it was cheaper and more stable and partly because the United Wireless Telegraph Company, the commercial company having the greatest number of stations at that time, controlled the use of the carborundum detector.

Also, the Government became active in the use of silicon and perikon (zincite and chalcopyrite). Galena and various combinations with zincite came into use. These crystal detectors have been used in greater number than any other since about 1907.

5. Audion. This form of detector was used to some extent as early as 1906, but apparently in very small numbers until about 1912 when the amateurs became active in its use, and within the last year or more it has been used to some extent by the Government.

The Tikker detector, not shown in the Chart, was mainly used in 1912 and 1913 for receiving constant amplitude waves.

6. Beat detector. This form of detector consists, in part, of a radio frequency, constant amplitude generator supplying a radio frequency differing from the frequency of the incoming, constant amplitude signals by such an amount as will produce audible beats. This appeared some time ago, to a very limited extent, in what was called the "heterodyne," wherein an arc produced the local radio frequency.

Within the last year or more, detectors, of which the audion is one type, have been arranged to act as detectors and local generators. This comparatively simple form of beat detector is taking the place of the tikker and increasing in number with the increase in use of constant amplitude transmitters.

The pliotron and other detectors and oscillators are increasing in numbers with the audion, particularly for beat reception.

These successive detectors, and the telephone method of reception, together with the subsequent improvements in telephone receivers and tuner circuits, have obviously contributed to radio service and to the rise of the range curve *R*, shown at the top of the chart.

All of the detector steps were markedly useful in radio development, but those recent steps of which the audion and pliotron are types (with their three-fold abilities, as detectors, generators and amplifiers), stand out as particularly useful. And the possibility of tuning to group frequency adds encouragement to the thought of better selectivity for the future.

7. The VIBRATOR INTERRUPTER used first as a means of breaking the primary current in the induction coil, because of its unreliability, small current carrying capacity, and slow operation was abandoned quite early by most United States users; the chief exception being the American Marconi Company, which brought it back into use in considerable quantity in 1912 in connection with the auxiliary 10-inch coil supplied by them and indicated under Factor 12. However, it has again been condemned and is passing out.

8. The MERCURY TURBINE INTERRUPTER replaced the vibrator to some extent. This interrupter was capable of giving a much higher interruption rate per second and to some extent was more reliable; however, the mercury required frequent cleaning and was somewhat expensive and injurious.

At the Avalon and Whites Point, California Stations, in 1902, rotating commutators were used. These were more reliable and gave higher interruption frequency than the vibrator.

9. The ELECTROLYTIC INTERRUPTER came with the mercury turbine interrupter, as a part of German made apparatus, supplied to the U. S. Navy in 1902. It, too, produced higher interruption frequency, but varied in action and became less satisfactory as its temperature increased and the acid used was injurious.

10. Early in 1903, Dr. de Forest brought an *alternating current generator and transformer* to the Navy Department at Annapolis. This was the beginning of the marked advancement in power and reliability at the transmitter. And the alternating current has lasted up to the present time.

The mercury turbine and electrolytic helped to increase the range and service, while the alternating current contributed to a greater and more lasting extent.

11. The Plain Antenna Transmitter was used by the United States Navy as early as 1899 at the Atlantic Highlands near New York and on vessels. At this time, it appeared with the vibrator interrupter and coherer detector.

12. The Plain Antenna Transmitter as an auxiliary was brought back by the American Marconi Company in 1912. The plain antenna transmitter was the characteristic transmitter of Marconi Companies.

13. The Tuned Coupled-Circuit Transmitters made by the Slaby-Arco Company of Germany were used by the United States Navy at Annapolis and on vessels in the Fall of 1902. Tuned coupled circuit transmitters later became the characteristic transmitters of the de Forest and United Wireless Telegraph Companies.

14. The Impulse Excitation Transmitters made by the Telefunken Company of Germany and by Dr. Seibt of Germany (then with the de Forest Radio Telephone and Telegraph Company) were put in use almost simultaneously in 1909. The Telefunken transmitters were used shortly thereafter by the Navy and Army. Later the quenched gap transmitters became known as the characteristic transmitter of the Telefunken Company.

15. Constant Amplitude Transmitters of the arc type were used in commercial radio Service in 1912, and have become known as the characteristic transmitters of the Federal Telegraph Company. The Goldschmidt alternator type came into service at Tuckerton in 1914, and the frequency-changing transformer type came into service at Sayville in 1915.

Before 1912, constant amplitude generators were built and experimented with in an endeavor to obtain serviceable machines, and for calibrating purposes.

The Radio Telephone has been experimented with in varying amount since about 1907, but up to the middle of this year it apparently has never been sufficiently marked in its usefulness to remain in Government or commercial use. Apparently the main reasons have been: 1: inability to construct a telephone transmitter (e. g. microphone) which would reliably

modulate sufficient energy; and 2: difficulty in obtaining constant amplitude current at short wave lengths or satisfactory spark frequency above audibility. The pliotron and similar devices may serve in solving these difficulties.

The word "radio" came into marked use in place of "wireless" in 1907, and was officially adopted by The Institute of Radio Engineers in 1911 and shortly thereafter by the United States Government.

16. WAVE METERS of German make were used by the Navy Department early in 1903, and stations were adjusted to prescribed wave lengths with increasing accuracy up to the present. Also, Navy records made about that time or shortly after show resonance curves. The wave meter was used in the United Wireless Company in 1907 and increased in use, until in 1910, practically all the United Wireless (the then largest commercial company) stations were adjusted by using the wavemeter.

17. RADIO AMMETERS came with the German apparatus to Annapolis in 1902 and the Navy has used such ammeters in increasing numbers since that time. Commercial organizations were slower to adopt these however. Within the last two years radio ammeters have been used in noticeably increasing numbers in commercial stations.

18. ANTENNA VOLTAGE increased from time to time up to the insulation limits as attempts were made, with different transmitters, to increase the power. The point of breakdown was quickly reached with the plain antenna transmitters, and this was one of the several objectionable features of the plain antenna transmitter. It may be that the insulation broke down more quickly with this type of transmitter because the antenna potential to ground remained high (before the spark discharge took place) for a greater length of time than where coupled circuits were used. For example, assuming that a coupled transmitter produced only alternating currents in the antenna and the potential rose from zero to a maximum and returned to zero again in one millionth of a second, while with the induction coil connected in the plain antenna circuit, the potential possibly increased from zero to a greater maximum for about one-tenth of a second before the discharge took place, the antenna insulation was subjected to higher potential for longer intervals.

19. ANTENNA SIZE. At first the vertical dimension of the

antenna was increased because it was recognized quite early that the sending range increased with the height of the antenna.

Later it was recognized that more power could be put in an antenna without breaking down the insulation by adding horizontal wires to the vertical antenna, and more power meant greater range.

Still later the antenna size was also increased to obtain natural periods more nearly equal to the longer transmitting wave lengths desired. An exception was the recent (since 1912) decrease in horizontal length of some shipboard antenna, to bring down the natural period so that the legal requirements for 300 meter waves could be met, as prescribed by the International Radio Conference.

In each step of development of the transmitter the size of the antenna was as a rule increased.

The plain vertical antenna grew from less than 100 feet (30 m.) to over 100 feet in height.

With the tuned coupled circuits at land stations in 1905, the height increased to over 200 feet (60 m.), and the horizontal dimensions were increased by fanning the wires and by increasing the number of masts. On shipboard, wider spreaders and more wires were used, increasing the capacity and *decreasing* the *resistance.*

With the impulse exitation transmitters, the height on land increased to 400 feet (120 m.) or more and the spread became greater; for example, in 1912, Sayville with its antenna, about 500 feet high and covering an area of about 4,000,000 square feet. With the constant amplitude transmitter came still larger antennas, for example, Tuckerton in 1914, with its antenna 850 feet (250 m.) high and covering an area of about 7,000,000 square feet.

An increase in height of about 10 to 1 occurred between 1899 and 1915, and a large increase in area with consequent capacity increase of about 25 to 1.

For future high power stations, right of ways may be obtained along roads or waterways and long antenna erected on high towers in one or more directions from the transmitter.

The single vertical wire antenna probably gave rise to the term "open circuit" while its use as plain antenna helped to stamp radio frequency circuits as "oscillating circuits." Apparently the term "open circuit" is passing with increased horizontal dimensions of antenna as also is "oscillating" with the advent of constant amplitude transmitters.

20. SPARK FREQUENCY increased from about 30 to 1,000 sparks per second during the period from 1899 to 1909. At Catalina, in 1902, about 70 sparks per second were used. In 1903, the 60 cycle alternating current brought the spark frequency to 120 or more per second. By 1905, apparently, spark frequencies as high as 500 per second were used. In 1909, spark frequencies of 1,000 per second and higher were used, particularly with quenched gap transmitters.

21. DECREMENT. The decrements of the alternating currents in the antenna have materially decreased since 1899.

Apparently, with practically all the steps in radio development tending to produce longer ranges and greater continuity of radio service, the effective power radiated increased with, and largely because of, the decrease in decrement. Or, probably, it may be said that the trend of transmitter development has been to increase the power and the size of the antenna and to produce single, radio frequency, constant amplitude (zero decrement) alternating current in the antenna.

22. UNIFORM COMMERCIAL APPARATUS. The era of standardization from the standpoint of having apparatus of fixed type was between about 1908 and 1912, with the peak equipment consisted of a power switchboard, motor generator of uniformity in apparatus at about 1910. The uniform (delivering 60 cycle A. C. and about 1 K. W.), open core transformer, rack with 12 jars, muffled open gap in a helix (direct coupled), two coil direct-coupled tuner, carborundum receiver, telephones, and flat top antenna (loop connected). This uniformity kept down first cost and maintenance, but it prevented material improvement, because improvement meant violation of uniformity and consequent raising of maintenance cost and because other vessels would want the same improvement thus resulting in the scrapping of apparatus without indication of sufficient compensation.

23. STOCK JOBBING. The exaggeration of radio matters in connection with the sale of "wireless" stocks of doubtful or practically no value was, as a rule, more or less associated with the operating commercial radio companies, from 1900 to 1911. As early as 1901, one company circulated printed matter and letters emphasizing the increase in telephone and telegraph stations and the great increase in selling price of telephone stocks and implying that the radio telegraph and telephone were ready to take the place of wire telegraph

and telephone. This company and subsidiary companies sold or attempted to sell stock. The same general process with amplifications continued to 1911 being promoted by several groups of people and under many names.

This stock jobbing influenced radio development in many ways; and whether or not this method was good, bad, or avoidable it certainly was an effective factor.

To sell stock required the showing of assets and activity. Patents and stations were considered as assets and activity. A patent was usually cheaper than a station which probably accounts for many radio patents.

Stations which were unprofitable from the standpoint of tolls or rental were established and maintained for and by the sale of stock.

Many steamship companies apparently only equipped their vessels with radio some years ago because it cost them little or nothing. By virtue of stock jobbing, the ocean-going public received more radio service and protection some years ago than it probably would have otherwise received, and the science and art were developed thereby. In the main, the general public paid the expenses without return of dividends or principle. It will be noted that curve L (land stations) drops at the beginning of the discontinuance of stock jobbing in 1910 and for similar reason the commercial ship stations, curve S changed direction in 1912.

Since 1911, the laws requiring and regulating radio have probably been the chief factors in fixing the number of ship and shore stations.

24. Post Office Prosecution. This result of stock jobbing reached its most active stage in 1910 and 1911, or about ten years after the stock jobbing started. About ten men were sent to the penitentiary and two or more were fined. These were later-day stock jobbers, the earlier stock jobbers had been out of radio long enough to be forgotten or to be protected by the statute of limitations before the continued and growing complaint from the public became effective. While the charges and convictions were specified under several counts and certain specific instances were brought up for proof, it possibly may be summed up by saying these men were punished for getting money from widows and poor people by flagrant misrepresentation about radio thru the United States mails.

25. Stock Sales to the public by stock jobbing methods were largely stopped in 1910 and 1911 by the Post Office prosecution; but, oddly enough, probably the greatest sale of radio stocks in the United States history occurred in 1912, when apparently about $6,000,000 changed hands in the sale of Marconi Wireless Telegraph Company of America stocks. The Marconi Company had raised its capitalization for taking over the United Wireless Company. Marconi stock was put on the market following the publicity attached to the Post Office prosecution and then the Titanic sank, further emphasizing radio. The result was old Marconi stocks went up in price from about $12 to $360 per share on the curb market and the new issue was sold.

Apparently some of the results of this new sale of stock to the public were to produce high power stations for trans-oceanic work, increase patent litigation, raise rentals to steamship companies, cause steamship companies to own and operate radio equipments, with some development of steamship apparatus by the Marconi Company.

26. Overland Radio was attempted in competition with the wire lines at one time or another in a majority of the states of the United States. In many cases the gross receipts were not sufficient to pay for the coal used in heating the stations. A large percentage of these stations were said to have been erected for stock jobbing purposes.

As a rule the overland stations were unable to handle business satisfactorily during the season of summer atmospheric disturbances, and the stations interfered with each other. In addition to this, they were competing with minor portions of two or three long established wire lines that were equipped to render service to nearly any point in the United States and to a great many points thruout the world, and the public was in the habit of using the wire lines. The result was practically universal abandonment of overland radio stations.

27. Operating Organizations have apparently varied from about 5 in 1902 to 10 at the present time, marked in earlier days by small short-lived companies, later by larger longer-lived companies with the more recent addition of operation by steamship companies.

28. Manufacturing Organizations. For a time, manufacturing companies were usually operating companies, but with the continued demand of the Navy and Army for

radio apparatus of U. S. manufacture and for improved apparatus, companies other than operating companies were formed to manufacture, and to meet this demand.

29. VALUE OF RADIO RECOGNIZED. In the earlier history except when convinced by a stock salesman, the public as a whole apparently regarded radio as more or less of a scientific toy which had possibilities but was not particularly useful; and because of stock jobbing, radio people, as a class, bore a somewhat bad reputation, both as to morals and ability.

The sinking of the "Republic" and the use of radio caused the public to recognize that it was of value, and its subsequent use (as, for example, on the S. S. "Ohio," and lastly, with the "Titanic") made such an impression that Congress passed laws requiring and controlling radio.

It may be said that from 1899 to 1911, the period characterized by stock jobbing, was the ERA OF DEVELOPMENT OF DEMAND FOR RADIO SERVICE, and with the coming of the Radio Laws and the stopping of stock jobbing in 1911 began the ERA OF FIXED MINIMUM DEMAND FOR RADIO SERVICE.

30. 50 PASSENGER, OCEAN LAW.

The first law passed, which became effective in July, 1911, required *ocean-going* vessels carrying *passengers* and carrying 50 or more persons, including passengers and crew, for a distance of 200 miles from United States ports to have a radio operator and apparatus capable of working 100 miles (160 km.). Additional stations principally on ships, were required, which offset somewhat the decrease in stations due to the closing of stock jobbing stations.

50 PERSONS LAW

In October, 1912, a revised law became effective for 50 persons which added one more operator and an emergency auxiliary source of power for the radio transmitter on ocean-going passenger ships; and later in 1913 on cargo and passenger carrying ships on the Great Lakes and on ocean cargo ships.

As will be noted in curve *S*, by the time all of these laws became effective the number of ship stations was approximately twice that of 1911 when the first law began to be effective.

In addition, these laws covering vessels carrying 50 persons required two licensed operators and an auxiliary source of power which increased the number of operators on commercial ships

to about four times that of 1911 and brought in the plain antenna auxiliary set and later the full power auxiliary set.

The licensing of the operators by examinations raised the technical training of the operators as a class.

The requirement for continual service and operative apparatus has improved the apparatus and provided far better radio protection for occasions of distress on vessels.

33. The DECREMENT LAW, or portion of the law, effective in 1912 with regulations, was made to prevent interference and for that reason required certain wave lengths and licenses for various classes of stations, all of which stations were required to use a decrement of less than 0.2.

34. FULL POWER AUXILIARY. This is an auxiliary source of power capable of furnishing sufficient power to operate the main radio transmitter for four hours or more. Two such installations were made early in 1911 by the United Wireless on the Lamport and Holt line. When the law requiring auxiliary sources of power went into effect, ten inch induction coils with small storage battery were put on by the Marconi Company, thereby providing less power for distress purposes than was provided for ordinary business. In 1913, the United Fruit Company installed large Edison storage batteries to furnish full power for their main transmitters and for emergency deck lights, and since then other steamship companies have been making somewhat similar installations.

35. PATENT LITIGATION. In August, 1902, the Marconi Wireless Telegraph Company of America brought suit against the de Forest Wireless Telegraph Company on the Marconi reissue patent number 11,913. Nearly three years later, in April, 1905, Judge Townsend held that claims 3 and 5 of the Marconi patent were infringed and granted an injunction and accounting on those claims, but said that claim 1 was too broad and claims 8, 10, and 24 were not infringed. However, in April, 1905, the de Forest Wireless Telegraph Company was a company of the past, and the decision practically only served to make others wary of claims 3 and 5. So that, altho the Marconi Company sued the American de Forest Wireless Telegraph Company in March, 1906 on claim 3 of this patent, the American de Forest Wireless Telegraph Company was using the loop antenna, and Judge Townsend rendered a decision in April, 1907, holding that the showing

made did not warrant the granting of an injunction. The chief result of this litigation which started in 1902 and ended in 1907, was the loop antenna, excepting, of course, that a considerable sum of money was probably expended. Taking into account all the radio litigation up to the present, probably the main features have been the expenditure of money and the time between the starting of the case and the final decision. This litigation effected the development of radio in a number of ways.

Beginning with 1902, one or more suits have been before the courts each year.

The decision in favor of the Marconi Company, plaintiffs, in 1905 resulted in the loop antenna which was successfully defended later.

The decision in favor of Fessenden and his associates, plaintiffs, in 1906 on the electrolytic detector, helped bring crystal detectors into use.

The decision in favor of the Marconi Company, plaintiff, in 1914, against the National Electric Signaling Company, and the National Electric Signaling Company suits against the Marconi Company apparently brought about the working agreement between these companies.

Seven suits filed in 1914 were the greatest number filed in one year.

Of approximately 27 suits filed from 1902 to the present time, apparently only seven have shown permanent status in favor of the plaintiff.

Of these, two were rendered ineffective by the defendant subsequently using other apparatus, two produced a working agreement, one was in connection with the selling out of the defendant, and the other two partially restricted two companies but are still being fought.

About eight suits are pending trial or decision.

Apparently United States radio patent litigation has been unprofitable for both the defendants and plaintiffs.

The time elapsed between filing the suit and the decision has varied from one month to four years and averaged about one and one half years.

36. Operation By Steamship Companies. That is, wherein the steamship companies rent or buy their apparatus, handle the traffic accounts, control their operators the same as the other members of their crews, etc. Among the first to do this was the United Fruit Company. Recently this

method of operation has increased quite rapidly, particularly on the Pacific Coast.

In the early days the stock jobbing operating companies rented the operators, apparatus, and traffic service for from $62.50 per month *down* to *nothing* per month. The steamship companies were not required to have it, and they were *not responsible* for it. Then, to the steamship company it was largely a *cheap* novelty which might be useful.

But with the departure of the low rent stock jobbing method, and the coming of some patent decisions and combinations in attempted patent monopoly, and the enforcement of radio laws, conditions have changed. Now, to the steamship company, it is more expensive and usually it is a *necessity* and a *responsibility*.

It has become a matter of question whether the steamship company cannot operate radio as cheaply as to rent its operation, and since it is now a *necessity* and a *responsibility*, the natural question is, why should not radio apparatus be in the same business system as other parts of the ship's equipment, the operator the same as any other member of the crew, and the traffic accounts the same as other traffic pertaining to ships? The result is that additional lines own and control the radio on their vessels.

37. THE INSTITUTE OF RADIO ENGINEERS. The Institute of Radio Engineers, formed by the combining of the Society of Wireless Telegraph Engineers and the Wireless Institute, was developed in the former organizations, principally by the persistent efforts of a few individuals. Practically, its early development was mainly characterized by the persistence of a few persons in meeting, reading, and discussing radio papers, regardless of attendance. Later, gradually, and still later, more rapidly, others became interested and active until now The Institute of Radio Engineers is an international, influential, educational organization, occupying a class by itself, and is worthy of classification as an effective factor in radio development.*

SUMMARY: The history of radio development in the United States is considered in great detail. Transmitters, detectors, antennas, a number of detailed parts of radio apparatus, and various branches of radio communication are classified, and their progress studied. Such topics as standardization, financial procedure, litigation, radio laws, and their consequences are treated fully.

* In this connection, it is a pleasure to inform the readers of the PROCEEDINGS that it is largely thru the loyal and continued efforts of Mr. Marriott that the originally very restricted membership of the Institute now runs into the thousands.—EDITOR.

DISCUSSION

Lloyd Espenchied: Mr. Marriott's paper is the story of the development of a new communication art, from the time of its inception, thru a varied probationary career up to a period in which it has become established upon a substantial service basis.

The value of the paper is considerably enhanced by the data given and by the manner in which it is graphically presented. This not only adds to its usefulness as an historical reference, but also injects an element of engineering importance, by showing up existing trends in the art and thereby enabling, by imaginary extrapolations of the curves, some insight to be had into the future.

As regards the trend in the technique of the art, the author's first chart illustrating the history of the development of transmitters, indicates clearly the tendency toward types giving a more and more frequent renewal of the antenna energy, i. e., toward the constant amplitude type of transmitter. The most intermittent type of transmitter (plain antenna) is already declining in numbers, while the next most intermittent type (ordinary coupled tuned circuit type) seems to have reached its growth and to have about started upon its decline. The impulse excitation type of transmitter representing the third step toward the constant amplitude type has taken up practically all of the growth of the more recent years and seems still to be growing. Altho the growth of the constant amplitude type has been slow up to the present, nevertheless from the trend indicated in the chart, and from our knowledge of its desirable transmission characteristics, we would be led to expect henceforth a more rapid growth in the number of such transmitters, in time accompanied by an actual decrease in the number of stations of other types.

Somewhat analogous trends are shown in the history of detector developments, starting as it does with the intermittently operated coherer, which accompanied the most intermittent type of transmitter, and coming down to the vacuum-tube-beat type of detector, co-operating with transmitters of the constant amplitude type.

Turning now to the curves of chart 2 showing the growth in the application of the radio art, we naturally wonder as to whether, for instance, the total number of stations will continue to grow at the same rate as in the past or whether it is approaching

the "saturation" point. Curve T, giving the total number of radio stations in the United States, shows a rapid rise for the last six or seven years. This curve is made up in greater part by ship stations, and the recent growth in such stations is very largely due to legislative enactment compelling their adoption. This has resulted in the rapid discounting of a growth which probably would have occurred naturally, tho more slowly, by the gradual recognition of the value of radio to the maritime world. Hence there is some question as to whether, in so far as it is due to ship stations, curve T may not soon fall off to a growth coincident with that of the maritime field itself. However, as regards total growth in an art as young as is radio, one should not lose sight of the possibility of enlargements in its sphere of economic utility brought about by scientific or technical advances either in it or in other arts as, for instance, that of aerial navigation.

February 15, 1917.

THE EVOLUTION OF THE THERMIONIC VALVE

R[eginald] L. Smith-Rose

THE EVOLUTION OF THE THERMIONIC VALVE.

By R. L. SMITH-ROSE, B.Sc., Student

(*Paper read before the* STUDENTS' SECTION, 22 *January*, 1918.)

SYNOPSIS.

I. Elementary thermionics.
II. The Fleming oscillation valve.
III. The De Forest audion.
IV. The Lieben-Reisz valve.
V. The pure electron discharge valves; the kenotron and pliotron.
VI. The use of the thermionic valve as a rectifier, amplifier, and generator of alternating currents.

I. ELEMENTARY THERMIONICS.

The term "thermionic" currents was first applied by Professor O. W. Richardson, in 1902, to the currents obtained by the emission of electricity from solid bodies raised to a temperature of incandescence. Since then the term has come into very general use in dealing with this subject, and the valves used for radio-telegraphy and other purposes, which depend upon this phenomenon for their action, are most suitably designated by the title "Thermionic," or more briefly, "Ionic Valves."

Although it is nearly 200 years since it was first observed that the air in the neighbourhood of red-hot metals is a conductor of electricity, the chief advance in our knowledge of this phenomenon has taken place during the last 20 or 30 years. Among the earlier investigators, Guthrie in 1873 was the first to call attention to the distinction between positive and negative electrification.* He showed that a red-hot iron ball in air could retain a charge of negative but not of positive electricity, whereas when the ball was raised to a white heat it could not retain either a positive or negative charge.

The first systematic investigations were carried out by Elster and Geitel † during the years 1882–9. They studied in great detail the charge acquired by an insulated metal plate mounted close to a metallic filament within a glass bulb, under different conditions of filament temperature and gas pressure.

When the gas is air or oxygen at atmospheric pressure, the metal plate receives a positive charge which increases as the temperature of the filament is increased, until this is at a yellow heat. As the temperature is raised above this point the charge diminishes until, with the filament at a bright white heat, the charge received by the plate is very small. When the pressure of the gas inside the vessel is reduced, the charge received by the plate diminishes, and as the exhaustion proceeds a point is reached at which the charge changes sign, and for high filament temperatures and low gas pressures the charge on the plate reaches a large negative value.

* *Philosophical Magazine*, 1873, Ser. 4, vol. 46, p. 257.
† *Wiedemann's Annalen*, 1882–1889.

Both the sign and magnitude of the electrification are influenced by the nature of the substance comprising the filament, and also by the nature of the gas. For example, Elster and Geitel showed that in hydrogen the plate acquired a negative charge, even at atmospheric pressure.

At the Philadelphia Exhibition in 1884 Edison exhibited a discovery made by him during his investigations upon incandescent electric lamps.* The phenomenon which has since become generally known as the "Edison effect" is briefly as follows :—

A small, insulated metal plate is sealed into an incandescent lamp between the legs of the horse-shoe-shaped filament. When the filament is made incandescent by direct current and a galvanometer is connected between the insulated plate and the negative end of the filament, practically no current will be observed flowing through the galvanometer; whereas if the galvanometer is connected between the plate and the positive end of the filament a current will be observed flowing through the galvanometer, in direction from the filament to the plate, the current amounting to two or three milliamperes under suitable conditions. Neither Edison nor Sir William Preece, who subsequently carried out some experiments on this effect, gave any explanation of the phenomenon, nor was any practical application made of it.

Professor J. A. Fleming † in 1890 showed that when the negative leg of the carbon loop was surrounded by a cylinder of either a metal or an insulating substance, the Edison effect almost entirely disappeared; and other experiments of a similar nature showed that the effect was due to passage of negative electricity from the incandescent filament to the cold electrode, an occurrence which Elster and Geitel, by a somewhat different method, had previously demonstrated in very high vacua.

Fleming also showed that the Edison effect is obtained, although to a very much smaller degree, when using platinum instead of carbon for the incandescent filament.

At this time the existence of electrons was unknown, and the flow of current between the incandescent filament and the metal plate was attributed to the passage of negatively charged carbon atoms. This view was also apparently supported by the fact that both carbons and platinum give off very fine dust if they do not actually volatilize at high temperatures, as shown by the familiar deposit of carbon or metal on the glass walls of an evacuated vessel in which a filament has been glowing for a long period.

* DYER and MARTIN: "Edison, his Life and Inventions," vol. 1.
† *Proceedings of the Royal Institution*, 1890.

In 1899, however, Sir J. J. Thomson announced his epoch-making discoveries concerning masses much smaller than atoms, carrying a charge of negative electricity, which were first called "corpuscles" but are now generally known as "electrons" and are still regarded as the ultimate units of negative electricity. These electrons were shown to be the carriers of the negative electricity in the cathode rays present in the high-tension discharge through a vacuum tube, and from measurements made in Sir J. J. Thomson's classical experiments it was shown that while each electron carries the same charge as that carried by a hydrogen atom its mass is equal to approximately only 1/1,800th of the mass of a hydrogen atom.*

Similar measurements showed that in the case of a carbon filament glowing in hydrogen at a very low pressure the negative electricity is given off by the filament in the form of free electrons.†

It was subsequently proved by Wehnelt that the electric current emanating from a lime-covered platinum cathode (the well-known Wehnelt cathode) is carried in the same manner by these negatively charged corpuscles,‡ and that the current from such a cathode is much greater than that obtained from the platinum alone.

Hence it may be said that when a metal or carbon filament is rendered incandescent in a highly exhausted vessel, there is a continual evaporation or emanation of negative electricity from it in the form of electrons, the rate of such emanation being dependent in the first place on the nature and temperature of the glowing filament, and on the nature and pressure of the surrounding gas.

This emission of electrons is readily explained by the electron theory, which assumes that these negatively charged corpuscles are disseminated through metals and carbon at all temperatures; they are in constant vibratory motion similar to that of the molecules of a gas, and are free to move in any direction under the influence of an electric force. These free electrons are normally retained within the metal by the electric force at the surface, which acts in a similar manner to the force at the surface of a liquid, tending to prevent the molecules of the liquid escaping into the region above it. If the velocity of any electron is sufficiently high its kinetic energy may be great enough to carry it through the surface layer, and so enable it to escape from the metal into the surrounding space. Since the average velocity of the vibratory motion increases rapidly with the temperature, then as the temperature increases, more and more of the electrons will be able to get through the surface layer and escape from the metal, the whole process being exactly analogous to the evaporation of a liquid with increasing temperature.

Applying the electron theory in this manner Professor O. W. Richardson found that the rate of emission of electricity from incandescent bodies could be expressed by an equation of the form

$$N = a\sqrt{T}\,e^{-bT}$$

* J. J. Thomson: "Conduction of Electricity through Gases," 2nd edition, chaps. v. and vi.

† J. J. Thomson: *Philosophical Magazine*, 1899, vol. 48, p. 547.

‡ Wehnelt: *Philosophical Magazine*, 1905, vol. 10, p. 80.

where N = number of electrons emitted per square centimetre of the hot body per second,
T = absolute temperature of the body,
and a and b are constants.

Richardson's measurements of the current obtained from a hot wire at different temperatures agree well with a formula of this form, and from his observations on different substances he gives the following values for the constants a and b *:—

For carbon: $a = 10^{34}$; $b = 9{\cdot}8 \times 10^4$.
For platinum: $a = 7{\cdot}5 \times 10^{25}$; $b = 4{\cdot}93 \times 10^4$.

These figures show that the emission from carbon is much greater than that from platinum. The rate of emission from tungsten at different temperatures, as calculated from an equation of the above form by Dr. I. Langmuir, is shown in Fig. 1.

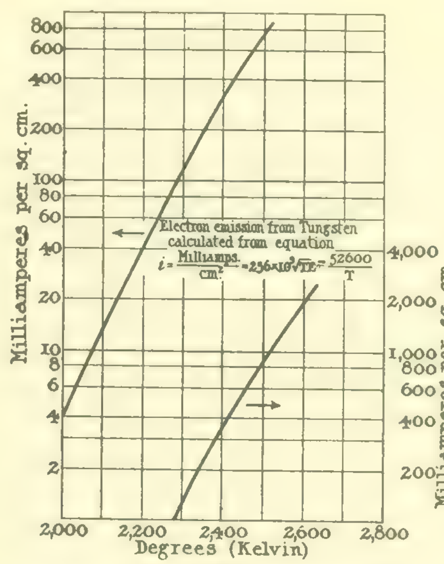


Fig. 1.

According to Richardson's theory an incandescent metal at any temperature emits electrons at a definite rate, which is independent of the electric field surrounding the hot body. If there is no electric field in the space surrounding the incandescent body, the electrons emitted return to the body and are re-absorbed. If, however, a positively charged body is brought near the heated solid, the electrons emitted will be drawn towards and absorbed by this body, their passage across the intervening space constituting an electric current flowing from the hot filament as cathode to the positively charged body as anode. The currents obtained in this manner were termed by Richardson "thermionic currents," a term which has since come into very general use.

If a negatively charged body is brought near the hot filament, the electrons will be repelled from it and will

* J. J. Thomson: "Conduction of Electricity through Gases," 2nd edition, p. 201.

ultimately return to the filament in a similar manner to the case in which there is no field external to the filament.

Viewed in this manner, the electron emission is independent of the flow of a thermionic current, the latter only taking place when a positively charged electrode is brought near the glowing filament. As the potential of this electrode is increased, an increasing proportion of the electrons will be attracted towards and absorbed by it, until finally a point is reached at which all the electrons emitted by the hot cathode are absorbed by the cold anode, and any further increase in potential of the latter will produce no increase in the current flowing to it. At this stage the thermionic current is said to be "saturated," and the magnitude of this current will be equal to the total charge carried by all the electrons emitted per second by the hot cathode.

The theory, as thus put forward, would apparently give a satisfactory explanation, both qualitative and quantitative, of elementary thermionic phenomena; but there are many experimental results which are not so readily explained and which have brought to light one important feature which must be borne in mind when comparing the theoretical with the experimental results. The above theory takes no account of the action of the gaseous atmosphere surrounding the hot cathode, and it has now been well established that, unless very special precautions are taken to exclude it, the residual gas present in our so-called high vacua exerts a very marked influence upon the thermionic emission from any heated body enclosed in an exhausted vessel.

For instance, it has already been stated that when a metal wire is heated to a dull-red heat the first effect consists in the production of positive ions round the wire, which increase in number as the temperature of the wire is raised up to a certain value. Above this value of the temperature, negative ions make their appearance, and these increase at a greater rate than the positive ions, until finally the sign of the resultant charge given off by the metal is negative. The presence of oxygen at pressures approaching one atmosphere favours the emission of the positive charge, while a diminished gas pressure or the presence of hydrogen has a marked effect in increasing the number of negative ions.

This action of the residual gas in the space surrounding the heated body, and a similar action due to the presence of slight impurities in the heated body itself, have been subjected to much investigation since Richardson first put forward his theory, and the results have emphasized the importance of taking these considerations into account. H. A. Wilson has shown that the electron emission from a hot platinum wire can be reduced to 1/250,000th of its former value by a preliminary boiling of the platinum wire in nitric acid to free it from the hydrogen which it so readily occludes on its surface.* The admission of a little hydrogen brought the current back to its former value. On one occasion during these experiments when a little phosphorus accidentally got into the wire the emission was enormously increased. In all cases, however, he found the variation of the emission with temperature could be expressed by the relation given above. Some experiments carried out by Pring and Parker in 1912 showed also that the thermionic currents obtained from incandescent carbon in a vacuum decreased to extremely small values as the carbon is very carefully purified and the vacuum improved.*

Richardson also has shown that the positive emission from a heated wire is of a transitory nature. If the metal is heated at a constant temperature, the emission of positive ions falls off rapidly with time, the rate of decay increasing rapidly as the temperature is increased.

The results obtained by these and other investigators led to considerable doubt being thrown on Richardson's theory, and it was suggested that the thermionic currents obtained in the majority of cases, if not all cases, were due to chemical action arising from the impurities in the heated wire or the gas surrounding it, and that if a perfectly pure metal were heated in a perfect vacuum there would be no electron emission from it.

A very common example illustrating how small is the electron emission from an incandescent metal in a high vacuum is afforded in the ordinary tungsten-filament incandescent lamp. The vacuum inside a tungsten lamp is very high, probably of the order of one-millionth of a millimetre of mercury after the lamp has been burning for some time, while the high efficiency of the lamp is due to the refractory nature of the metal (tungsten), enabling it to be run at such a high temperature without fear of its melting. It is evident that in the ordinary lamp the current flowing from one part of the filament to the other must be very small, whereas according to Richardson's equation and experimental results the thermionic emission from tungsten at temperatures near its melting point might amount to several amperes per square centimetre of its surface.

Dr. Irving Langmuir, however, has recently studied in great detail the thermionic currents from tungsten filaments in extremely high vacua, the pressures used being of the order of one-millionth of a millimetre of mercury or less; and he has shown that the smallness of the currents previously obtained was due not to the failure of the filament to emit electrons but to the potentials applied to the anode being insufficient to enable the space surrounding the filament to carry the currents which could otherwise be obtained.† As a direct result of his investigations he concludes "that the electron emission from heated metal is a true property of the metals themselves and is not, as has so often been thought, a secondary effect due to the presence of gas."

In a typical experiment of Dr. Langmuir's two single-loop tungsten filaments were mounted in a bulb, which was then exhausted to the highest possible degree, utilizing special methods of exhaust and of treating the electrodes to free them from all occluded gas. One of the filaments was heated by the electric current and was used as the cathode, while the other filament served as the anode. A constant positive potential

* H. A. WILSON: *Philosophical Transactions*, 1903, vol. 202, p. 243.

* PRING and PARKER: *Ibid.*, 1912, vol. 23, p. 192.

† I. LANGMUIR: *Proceedings of the Institute of Radio Engineers*, 1915, vol. 3, p. 261; *General Electric Review*, 1915, vol. 18, p. 327; and *Electrician*, 1915, vol. 75, p. 240.

was applied to the anode in series with a galvanometer, and by varying the cathode heating current, the relation between the thermionic current measured by the galvanometer and the temperature of the cathode was obtained and plotted in the form of a curve. This curve representing the thermionic current as a function of the temperature consisted essentially of two parts: during the first part the current increased according to Richardson's equation, and was independent of the voltage and of the shape and size of the anode; whilst during the second part of the curve the current was influenced by both of these factors. If the dimensions of the anode and its potential are maintained constant the current finally reaches a saturation value, and any further increase in temperature of the cathode produces practically no increase in the thermionic current. The

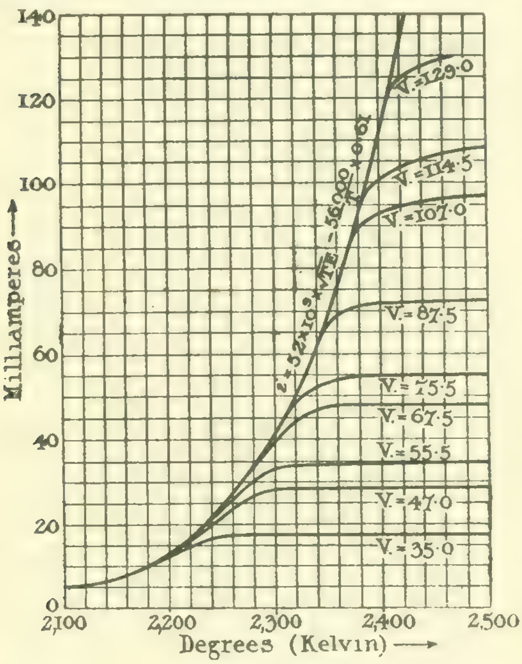


FIG. 2.

greater the potential at which the anode is maintained, the greater will be the value of the saturation current, and the higher will be the temperature to which the cathode must be raised before this saturation value is reached.

Fig. 2 shows a typical set of current-temperature curves obtained in the manner described above for different voltages applied to the anode. It will be observed that the early parts of all the curves coincide with the curve plotted from Richardson's equation.

This limitation of the thermionic current by the potential applied to the anode was found to be due to the electrons carrying the current constituting an electric "space charge" between the electrodes, which repelled the electrons escaping from the hot filament causing them to return to it. Langmuir has calculated the effect of this space charge, and finds that in any bulb the maximum thermionic current that can be carried by the space between the cathode and anode is proportional to the potential difference between the electrodes raised to the power 3/2, and his experimental results are in complete accordance with this law in the cases where the vacuum is so high that there is no appreciable positive ionization within the bulb.*

The presence of a very minute trace of gas within the bulb, however, may lead to the formation of positive ions sufficient to neutralize to a large extent the electronic space charge, and so greatly increase the current-carrying capacity of the space. For instance, the presence of mercury vapour at a pressure of 10^{-5} mm. has been found, under suitable conditions, completely to neutralize the effect of the space charge, so that a current of 0·1 ampere was obtained with 25 volts on the anode, whereas without the mercury vapour a pressure of over 200 volts was necessary to draw this current through the space.

Apart from this enormous effect on the current-carrying capacity of the space, the presence of a gas or vapour within the bulb exerts a considerable influence upon the thermionic emission from the cathode. But Langmuir found, contrary to the previously generally accepted opinion, that when the cathode is of pure tungsten the effect of any gas present is to decrease rather than increase the electronic emission. For example, it is found that the presence of oxygen, or a gas containing oxygen such as water vapour, at a pressure of 10^{-6} mm. will cut down the electronic emission to a small fraction of the value obtained in a high vacuum.

This reduction of the emission by the presence of a gas is probably due to some chemical action, for it has been found that the inert gases of the argon group produce no such effect, and this fact has been employed in one type of rectifying valve to obtain neutralization of the space charge effect without reducing the electron emission from the tungsten cathode.†

Having thus briefly reviewed the progress of our knowledge of the subject of thermionics, we will now proceed to consider the application of this knowledge in the various types of thermionic valves used for the rectification, amplification, and generation of alternating currents.

II. The Fleming Oscillation Valve.

Professor J. A. Fleming in 1904 was the first to apply these phenomena of thermionics to the rectification of alternating currents, whether of high or low frequency.‡ The device which he made to effect this may take one of several forms, some of which are shown in Fig. 3. It consists of an ordinary carbon-filament incandescent lamp provided with a separate insulated electrode, in the shape of a flat or cylindrical metal plate, or another carbon filament sealed into the bulb. When the carbon filament is rendered incandescent by a source of electric current, it will be found that a single cell will pass a current through the vacuous space between the in-

* I. LANGMUIR: *Physical Review*, 1913, vol. 2, p. 450.

† G. S. MEIKLE: "The Hot Cathode Argon Gas-filled Rectifier," *General Electric Review*, 1916, vol. 19, p. 297; and *Electrical Review* 1916, vol. 78, p. 472.

‡ See British Patent No. 24,850, 1904.

sulated electrode and the hot filament, provided that the negative pole of the cell is connected to the negative side of the filament. If the connections of the cell are reversed, practically no current passes, the small amount of current obtained being due to positive ions formed from the residual gas in the bulb. This is what we should expect from the fact that the hot filament is emitting negatively charged particles, and in order to

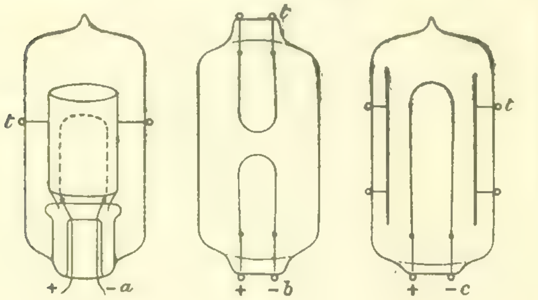


FIG. 3.

draw these across the gas space to the cold electrode the latter must be raised to a positive potential with respect to some portion of the incandescent filament.

The space between the cold and hot electrodes, therefore, possesses unilateral conductivity and the arrangement acts as an electrical valve, passing electric currents in one direction but not in the opposite direction.

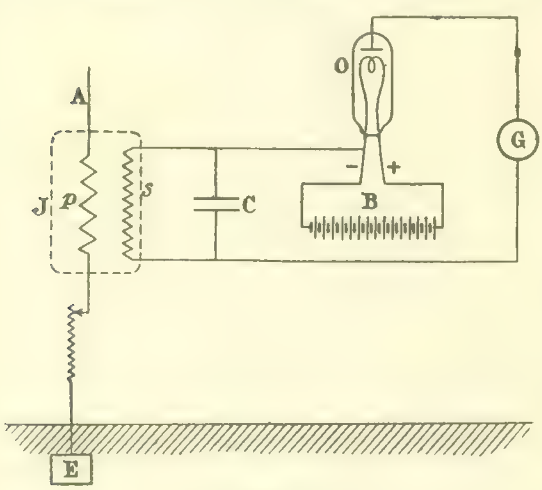


FIG. 4.

Fleming next found that this device could be used to convert electric oscillations into unidirectional currents, which may then be detected by means of an ordinary galvanometer.

The arrangement of connections for effecting this is shown in Fig. 4. The oscillation valve O has a sensitive galvanometer G placed in series with the secondary coil S, of an oscillation transformer connected between its metal plate or second electrode and the negative terminal of the carbon filament. If electric oscillations are induced in this secondary circuit by a primary coil p, then, when the carbon filament is rendered incandescent by the battery B, only one-half of the oscillatory current is allowed to pass through the gas space, viz. that in which the movement of the negative electricity is from the carbon filament to the second electrode. The galvanometer has passing through it a flow of electricity in one direction and its coil or needle will therefore be deflected.

For use as a receiver in radio-telegraphy, the primary coil p is connected in the antenna circuit between the aerial wire A and the earth connection E. The secondary circuit of the oscillation transformer is closed by a condenser C, adjusted to give resonance with the frequency of the incoming waves. The valve is connected as shown in the diagram, a telephone being inserted at G to give audible reception of signals.

The incoming electric waves excite oscillations in the antenna, which are transferred to the secondary

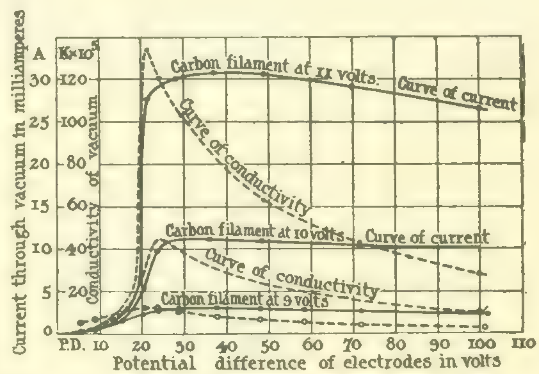


FIG. 5.

circuit S C. These oscillations are rectified by the unilateral conductivity of the vacuum valve, and each train of oscillations produces a single unidirectional rush of electricity through the telephone receiver, causing a click.

The receiver diaphragm will therefore vibrate at a frequency equal to that of the trains of oscillations received, that is, equal to the spark frequency of the wireless telegraphic transmitter from which the signals are being received. The sound heard in the receiver will therefore be a low buzzing tone or a high musical note, according to this spark frequency, and the tone will be cut up into the dots and dashes comprising the signals, as sent out by the transmitting key.

While this property of unilateral conductivity enables us to use the Fleming valve as a rectifying detector of electric oscillations, we may also make use of it in another manner, depending upon the fact that the gas space inside the bulb does not obey Ohm's law as a conductor.

If we apply a steadily increasing electromotive force between the second (cold) electrode and the filament (cathode), we find that the current does not increase uniformly, but rises fairly quickly to a maximum value

(the saturation current for the gas space), after which it falls off very slowly. Corresponding to this, the conductivity or the ratio of current to voltage in the gas space rises to a maximum and then falls off.

Fig. 5 shows the current and conductivity curves obtained by Professor Fleming for an oscillation valve with a metal cylinder surrounding the carbon filament, the latter being heated to different temperatures. The valve is more completely unilateral the colder the metal cylinder is kept, for obviously if we allow this cylinder to become heated by radiation from the filament, it will itself commence to emit ions and the current between the filament and the second electrode will not be entirely in one direction.

Now it will be seen from the current-voltage characteristics that the curvature is not constant, and we can find a point near the "knee" of the curve at which the slope of the curve on one side of the point is much greater than that on the other side. This point corresponds to a certain steady voltage applied between the plate and the filament, and a corresponding steady current flowing through the valve, and the difference in slope of the curve on the two sides of the point indi-

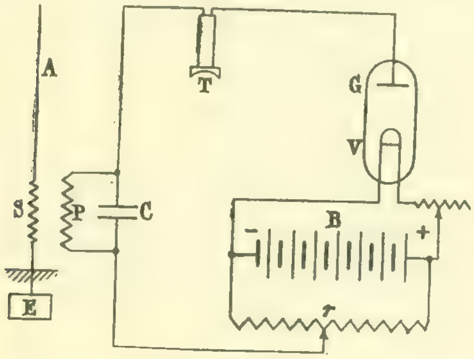


FIG. 6.

cates that if the potential difference between plate and filament be alternately increased and decreased by a small amount, the corresponding increase in current through the valve in the one case will be much greater than the decrease in current in the other case.

If this alternate increase and decrease in voltage is effected by superimposing an alternating voltage on the steady voltage, then the corresponding currents have a mean value which is greater than the current corresponding to the steady voltage alone. Hence if we have a telephone receiver in series with the valve plate circuit, under these conditions a click will be heard in the receiver every time the alternating voltage is applied to the valve electrodes.

We can therefore apply this property of the valve having a non-linear characteristic to the detection of electric oscillations, the circuit arrangements being as shown in Fig. 6. One side of the oscillation circuit PC is connected in series with a telephone T to the second electrode of the valve, whilst the other side is connected to the sliding contact on the resistance *r* shunting the battery B which supplies the heating current for the filament. By this means we are able to apply an adjustable steady voltage across the gas space in the valve and also, from the oscillation circuit, superimpose on this an alternating voltage of frequency equal to that of the oscillations set up in the coupled antenna circuit.

If, therefore, we adjust the slider on the resistance *r* so that the voltage applied to the valve corresponds to the point on the characteristic curve at which a sudden change of curvature takes place, then every time oscillations are set up in the circuit PC the effective value of the current through the telephone will be increased and a click will be heard in the receiver. Thus when the complete circuit is adjusted to receive radio-telegraphic signals, the tone heard in the receiver will be of a frequency equal to that of the trains of electric waves received, i.e. equal to the frequency of the spark at the transmitting station.

With a good valve and by carefully adjusting the conditions under which it is operating, Fleming found that this arrangement provides a more sensitive detector than that employing the unilateral conducting property of the valve.

Fleming found later that greatly improved results were obtained when the valve was constructed with a tungsten filament and an insulated copper cylinder surrounding it.* This is due to the fact that the tungsten can be raised to a much higher temperature than carbon without volatilization and gives a much greater electronic emission; and as will be seen later on in the paper, this type of thermionic valve is almost universally constructed at the present time with either a tantalum or tungsten filament.

III. The "Audion" Detector and Amplifier.

The next step in the evolution of the thermionic valve was made by Dr. Lee de Forest and consisted in the introduction of a third electrode into the evacuated bulb. Lee de Forest had been working on the simple rectifying valve containing a metal or carbon filament and one insulated electrode (already described) at practically the same time as Fleming, and his results were first described in a paper before the American Institute of Electrical Engineers in October 1906.† Considerable controversy has since then ensued as to the relative priority of the inventions of the Fleming valve and the audion, the name assigned to the valve by De Forest; but this has now been settled in favour of Fleming for the original valve, Lee de Forest having the credit of introducing another insulated electrode into the bulb, thereby transforming it from a rectifying valve into a kind of gas relay having an amplifying effect on the received oscillations.

This modification was described by De Forest in 1913 before the Institute of Radio Engineers.‡ This third electrode consists of a metal strip or wire bent into the form of a grid, and situated between the filament and the second electrode or plate, and it serves as an independent

* British Patent No. 13,518/1908.

† *Transactions of the American Institute of Electrical Engineers*, 1906, vol. 25, p. 735; and also *Electrician*, 1906, vol. 58, p. 216.

‡ *Electrician*, 1913, vol. 72, p. 285.

path by which the electric oscillations are introduced into the vacuous space within the bulb.

In studying the action of this grid we may consider the diagram given in Fig. 7, which shows a simple method of connecting up the audion for the reception of electric oscillations.

The incandescent lamp bulb contains a tantalum filament F, which is lighted by a battery B of 4–15 volts. Close to one side of, and parallel to the plane of, the filament is mounted a small rectangular nickel plate P. This plate is connected through the telephone receiver R to the positive terminal of the dry-cell battery B_2, giving from 15 to 40 volts, the negative terminal of this battery being connected to the positive side of the filament. Between the filament and the plate is mounted the third electrode G, a grid-shaped wire or perforated plate of nickel, at approximately 1/16 inch from both the plate and the filament. Leads from the condenser C_2, in series with the grid G, and the negative end of the filament are connected to the terminals of the variable condenser C_1, which is adjusted to place the circuit L S C_1 in resonance with the received oscillations induced in the coil L S.

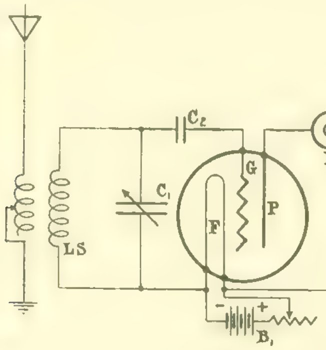


FIG. 7.

Now when no signals are being received, the grid will be practically at the same potential as the negative side of the filament, which we will regard as our zero of potential, and a certain steady current will be flowing through R in the plate circuit, the value of the current depending upon the dimensions of the valve and electrodes, the temperature of the filament, the nature and pressure of the gas, and the voltage of the battery B_2.

If now the grid be raised to a positive potential with respect to the negative end of the filament, the intensity of the electric field between G and F will be increased, and more negative ions will be drawn across this space than previously. Some of these will be drawn into the grid, giving a small current in this circuit, but the majority of them will pass through the perforations in the grid and will subsequently be attracted to the plate under the field created by the battery B_2. The net result, then, of imposing a positive potential on the grid will be to increase the current in the plate circuit, and, within certain limits, the greater the potential on the grid the greater is the increase in current. Similar reasoning will make it evident that the effect of raising the grid to a negative potential with respect to the negative side of the filament will be to decrease the current in the plate circuit.

A typical characteristic curve for an audion valve, showing the variation of current in the plate circuit with the potential applied to the grid, is shown in Fig. 8. Normally the grid is practically at zero potential, indicated by the point P on the curve.

Now when electric oscillations are induced in the circuit L S C_1, from the receiving aerial circuit, these are rectified between the grid and the filament and accumulate a negative charge on the grid and the connected plate of the condenser C_2. This decrease of the grid potential causes a corresponding decrease in the plate current, as indicated by the above curve. As the train of oscillations dies away, the charge on the grid leaks away relatively slowly by means of the positive gaseous ions within the bulb, thus allowing the plate current to return to its normal value. This function takes place for every train of damped oscillations received, and hence the current in the telephone receiver alternately decreases and re-assumes its normal value, at a frequency equal to that of the spark at the

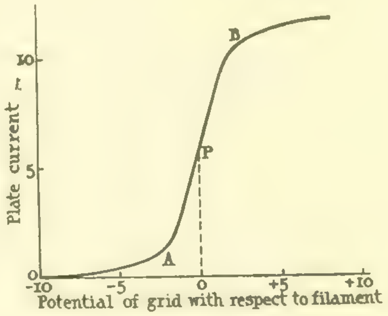


FIG. 8.

transmitting station, and the telephone diaphragm will therefore vibrate at this same, audible frequency.

This three-electrode valve may also be used as a detector without employing the grid condenser C_2. In this case the grid potential is maintained normally at one of the bends A or B of the curve in Fig. 8 by means of a separate adjustable battery. Then as the incoming oscillations cause the grid potential to vary alternately on either side of this value, the resulting changes in plate current, on account of the asymmetry of the curve, are not symmetrically alternating about the normal value but have a direct current component. Hence each train of oscillations received produces a unidirectional impulse through the telephone receiver and the diaphragm of the latter will vibrate at the spark frequency of the transmitter.

Whichever arrangement is used, the result will be the same in that a note of audible frequency will be heard in the receiver, cut up into dots and dashes in accordance with the signals sent out by the transmitting key.

The intensity of the sound depends upon the voltages

of the batteries B_1 and B_2, and the best position can be found by adjusting these while listening to the note received. When the best adjustment has been obtained it will be found that the intensity of the received signals is several times as great as those which would have been obtained by connecting the receiver directly in the receiving circuit, showing that this audion valve has acted in a true sense as an amplifier of the received signals, exerting a kind of relay action quite distinct from the simple rectifying properties of the Fleming valve. The audion, however, differs from the most perfect contact relay device in giving a quantitative response, that is to say, up to the saturation currents for the gas space within the bulb the change in plate current is approximately proportional to the grid voltage.

Lee de Forest made numerous experiments with tungsten and other filaments, with platinum coated with alkaline metals or salts, and with various gases and vapours in the bulb, but did not succeed in increasing the sensitiveness obtained with a tantalum filament and atmospheric air exhausted to the highest vacuum. He found that the best value of the battery (B_2) potential to procure the maximum sensitiveness depended upon the degree of evacuation, being roughly proportional to the same.

When the voltage of this battery B_2 is sufficiently raised, the ionic discharge from the hot filament cathode becomes visible in the form of a blue glow, occupying practically the whole bulb. A similar blue glow may be brought about in normal working if a powerful spark discharge occurs in the neighbourhood of the audion, causing a momentary large potential to be impressed upon the grid. The appearance of this blue arc is always a sign that the bulb is being over-run as regards the current passing from plate to filament. In this connection an interesting phenomenon may be observed in certain bulbs when the voltage of the battery B_2 in the plate circuit is adjusted until the blue glow is just visible round the edges of the plate. Then, when powerful impulses are received on the grid, a momentary flaring out of this blue aura can be observed with each signal, so that it is possible to read the telegraphic signals by sight.

The possibility of this blue glow effect, together with other properties due to the presence of some remanent gas in the bulb, gives rise to certain irregularities in the working of the audion, which place it at some disadvantage compared with a modified form, much more highly exhausted, to be described later. The presence of the blue glow is also very detrimental to the life of the valve, owing to the disintegration of the filament caused by the intense bombardment by the positive ions.

A great advantage which this thermionic valve amplifier has over any other relay device, is that there is no lower limit of sensitiveness; for, if the original impulse received is too minute to be directly discernible it may be amplified one or more times, and the effect of the original impulse will be observed to exist. The simplest arrangement of connecting two amplifiers in cascade to obtain increased magnification is shown in Fig. 9. A step-up transformer T_1 is provided if the original impulses coming from *s* are of low voltage, the secondary winding being connected across from the grid to the filament of the first valve as shown. In the plate circuit of this valve is included the primary of the transformer T_2, the secondary winding of which transfers the amplified impulses from the first valve to the grid circuit of the second. Similarly, valve No. 2 may actuate a third, and so on, the successive steps requiring as a general rule larger bulbs with larger heating areas and electrode surface to carry the increasing currents. In this manner the received signals after having been rectified to the form of impulses of audible frequency may be further amplified several times, the alternating potential applied to the grid of each valve producing synchronous amplified variations in the corresponding plate current, in accordance with the sloping part of the characteristic curve in Fig. 8. The receiver placed in the plate circuit of the last valve will then be operated with the total amplified current obtained from the original impulse.

De Forest, making measurements of the amplification by the shunted received method, found that a good bulb gives an amplification of five times, and with three in cascade he obtained a magnification of 120 times, this including the losses in the three transformers in circuit.

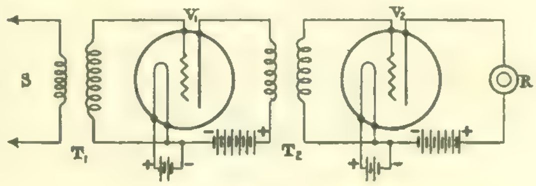


FIG. 9.

The audion has a further advantage as a magnifier in the absence of any periodic or very delicate adjustment, and also in its freedom from the effects of mechanical vibration or disturbances.

The immediate use of this valve for amplifying, and rendering readable, signals which were previously inaudible, will be obvious, giving, as it does, a greatly increased receiving range for any wireless station.

IV. The Lieben-Reisz Valve.

At about the same time that De Forest was investigating the three-electrode valve, Messrs. Lieben and Reisz were carrying out experiments in Vienna on a gas valve containing a somewhat different form of ionizer, utilizing the fact discovered by Wehnelt in 1904, that strongly heated oxides of certain metals, particularly those of calcium and barium, emit electrons at very low voltages.*

Willows and Hill described some experiments in 1911, making use of this fact to obtain increased ionic emission and sensitiveness in a modified form of Fleming valve.† They used electrodes of platinum, both of which could be heated by a current. The cathode was coated with calcium oxide (lime) which emits negative electrons on being raised to a white heat, while the anode was

* WEHNELT: *Philosophical Magazine*, 1905, vol. 10, p. 80.
† WILLOWS and HILL: *Electrician*, 1911, vol. 68, p. 302.

covered with aluminium phosphate, which gives out positive ions when raised to a dull red heat. They found that this method gave improved rectification and greater sensitiveness than the ordinary Fleming valve.

The final form of the Lieben-Reisz valve was described by one of the inventors in 1914.* The arrangement of the connections is shown in Fig. 10.

The Wehnelt cathode K consists of a platinum strip 1 metre in length, 1 mm. wide and 0·02 mm. thick, wound in a zigzag form upon a glass support, the strip being coated with a thin layer of calcium oxide or barium oxide. The grid G is a circular aluminium plate perforated with holes about 3·5 mm. diameter, while the anode A is a short spiral of 2 mm. aluminium wire.

The three electrodes are mounted in an evacuated glass vessel of the shape illustrated, the approximate dimensions of the valve being 16 inches long by 4 inches maximum diameter.

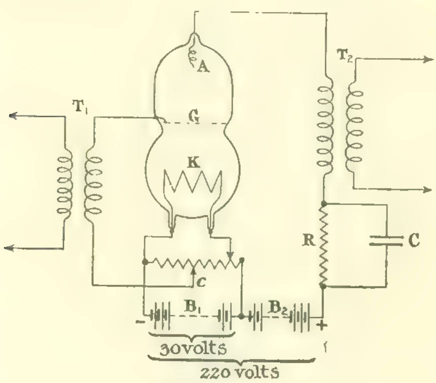


FIG. 10.

The cathode is brought to a bright-red heat at a temperature of about 1,000° C. by a battery B of about 30 volts. A certain steady voltage is impressed upon the grid from the sliding contact *c* on the potentiometer connected across the heating battery. The current to be magnified is led to the grid through the transformer T_1, the amplified current being drawn from the secondary of the transformer T_2. The necessary working voltage in the anode circuit is about 220, and a resistance R is included to prevent too great an increase in the discharge current, a condenser shunt being provided for the amplified alternating current.

In the early experiments it was found difficult to obtain a uniform discharge owing to the variation of the gas pressure inside the tube, this giving varying sensitiveness and entailing constant adjustment of the grid and heating voltages. It was therefore decided to replace the gas discharge by a vapour discharge, by introducing mercury vapour into the tube, constancy of pressure being obtained by keeping a small quantity of liquid mercury in a small side tube attached at the bottom of the main tube.

Actually in the final form of the valve an amalgam of mercury with a lower vapour pressure is used, as the vapour pressure of mercury rises rapidly at temperatures above 20° C., this giving rise to high current densities at the cathode sufficient to cause fusion of the platinum strip.

Although the discharge is maintained by the glowing oxide cathode, the majority of the current is carried by the mercury vapour, and thus the ageing of the tube due to the occlusion of the residual gas is very small, and a life of from 1,000 to 3,600 hours is obtained.

The inventors claim an amplification of 33 times for this type of valve, independent of the amplitude of the primary current, and that, using four such valves connected in cascade, alternating currents of frequencies ranging from 2,000 to 8,000 cycles per second have been magnified 20,000 times with perfect reproduction of the original wave-form.

This form of gas relay has been adopted by the A.E.G. and is used by the Telefunken Company as an amplifier for received radio-telegraphic signals; but it is probable that the large size of the tube and the high voltages required to operate the valve will seriously limit its field of application in spite of the high value of the magnification obtained.

V. The Pure Electron Discharge Valve.

In the types of valves already described, employing the thermionic currents obtained in an evacuated bulb, the latter always contained a certain amount of residual gas. In this respect we must state that a pressure of the order of 1/10,000 mm. of mercury indicates that a relatively large amount of residual gas is present in the bulb. This residual gas, as we have seen, had a very considerable influence on the operation of the valve in supplying positive ions within the bulb, which neutralized to a great extent the space-charge effect of the electron currents between cathode and anode, and enabled comparatively large thermionic currents to be passed under potentials of 50 volts or less. But the presence of gas to this extent within the bulb has been found to carry with it certain disadvantages. In the first place, the characteristics of the valve tend to become very irregular, the current-voltage curve often showing decided kinks at moderately high voltages. In many cases also, when working at high cathode temperatures and at high anode potentials, the discharge becomes very unstable at certain points and the characteristic for increasing voltages is somewhat different from that in the reverse direction. All these effects, moreover, vary with the composition and pressure of the contained gas, and both these vary with the intensity and duration of the discharge passing through them, the pressure decreasing considerably after a time, similarly to the manner in which an X-ray tube becomes "hard" after prolonged use. Another effect of the positive ionization within the valve is the tendency to disintegrate the cathode by the bombardment of the positive ions, and so considerably diminish the life of the valve.

Most, if not all, of these defects are absent in the pure electron discharge type of valve, which is the outcome of the investigations of Dr. Langmuir in

* REISZ: *Electrician*, 1914, vol. 72, p. 726.

the General Electric Company's Research Laboratory at Schenectady, N.Y. In this valve the evacuation of the bulb is carried out to the highest possible degree, to eliminate all possible ionization, in which case, as shown by Langmuir, the electron emission from the cathode follows Richardson's equation absolutely, and the corresponding thermionic currents can be obtained provided that sufficient voltage is applied to the anode to overcome the space-charge effect of the electron stream from the cathode.

To distinguish this type of valve from those containing some residual gas, the term "kenotron" has been applied to it. This name has since become generally applicable only to the form of the valve containing two electrodes, and used as a rectifier, the term "pliotron" having been designated to a kenotron provided with a third electrode or grid to convert it into an amplifier of alternating currents.

As an example of the first use of a kenotron, mention may be made of the X-ray tube invented by Dr. W. D. Coolidge in 1913.* In this tube the cathode is formed of a small flat spiral of tungsten wire surrounded by a cylindrical sleeve of molybdenum which serves as a focusing device, while the anode, or target, consists of a massive piece of wrought tungsten supported near the centre of the tube by a molybdenum rod. The tube is exhausted to the highest degree in the manner described below, and the vacuum is such that, unless the filament is heated, the tube shows no conductivity in either direction even with a voltage as high as 100,000. With the filament heated, the tube can be used for the production of X-rays with voltages as high as 200,000, and the intensity of the discharge can be completely controlled by varying the temperature of the cathode. The current through the tube is absolutely unidirectional owing to the absence of gas, and there is no heating of the cathode by the discharge current, and no evidence of any disintegration of the cathode. These factors enable the tube to be run continuously at a high energy input, while the intensity of the discharge remains absolutely constant. In ordinary use the temperature of the filament is so low as to prevent any appreciable evaporation or deterioration, giving the tube an almost unlimited life.

Dr. S. Dushman † has described other forms of the kenotron used for the rectification of alternating currents. These can be constructed with a thermionic current-carrying capacity up to 0·5 ampere, the filament being run at a temperature in the neighbourhood of 2,500° K., at which the life of the valve is approximately 2,000 hours. Since the characteristics of the kenotron are positive and perfectly stable, several of these instruments can be run in parallel and each one will take its proper share of the current. By this means the rectification of very large currents can be carried out. In his paper, Dushman reproduces some oscillograms which show the limitation of the thermionic current, first by the potential applied to the anode, and secondly by the temperature of the cathode. These oscillograms also show the perfect rectification obtained with this type of valve. A typical form of the kenotron for use up to 50,000 volts is illustrated in Fig. 11, the filament being mounted between two parallel plates, together forming the anode; this arrangement is used in order to balance as far as possible the electrostatic forces between the anode and the filament, which may become very great at high voltages and tend to pull out and break the filament.

* W. D. COOLIDGE: *Electrician*, 1915, vol. 74, p. 505; British Patent No. 14,892/1913.

† S. DUSHMAN: *General Electric Review*, 1915, vol. 18, p. 156; and *Electrician*, 1915, vol. 75, p. 276.

The general construction and use of the pliotron, containing three electrodes, is described by Dr. Langmuir in his paper before the American Institute of Radio Engineers in April 1915 * and also in the patent †

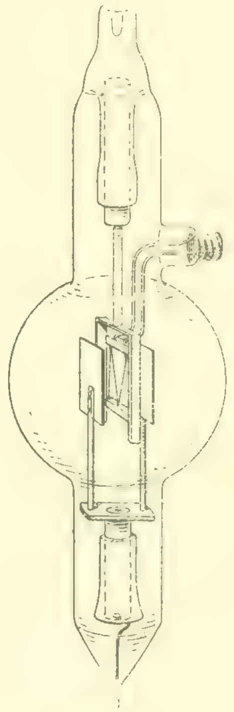


FIG. 11.

covering this invention. The general arrangement of the three elements is very similar to that employed in the De Forest audion, the details being modified according to the use for which the valve is required. The filament is of tungsten wire, and is usually either in the form of an inverted V or stretched straight between the supporting wires. The second and third electrodes are of nickel wire and plate respectively, and with the V-shaped cathode are arranged on either side of this in parallel planes as illustrated in Figs. 12 and 13. In the other form the grid is formed of a cylindrical spiral of nickel wire around the filament as axis, the plate forming a co-axial cylindrical sheath surrounding both grid and filament.

* I. LANGMUIR: *General Electric Review*, 1915, vol. 18, p. 327; and *Electrician*, 1915, vol. 75, p. 240.

† British Patent No. 15,788/1914.

When these elements have been mounted in the tube the latter is evacuated by the most approved methods of electric lamp exhaust, using either the Gaede molecular air pump,* or better, the mercury condensation pump as developed by Langmuir.† The first evacuation is carried out with the whole valve heated in a

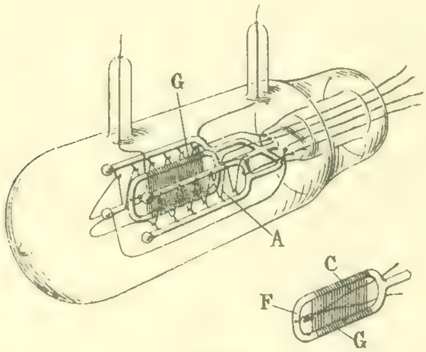


FIG. 12.

suitable furnace to the highest temperature that the glass will stand without softening, in order to remove as much as possible of the gas and vapour occluded on the walls of the vessel. It is desirable too that all the electrodes should be heated electrically if possible, to a temperature of about 2,500° C. But this heating

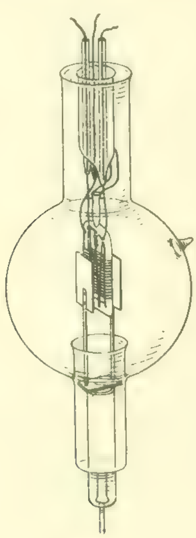


FIG. 13.

alone will not remove all the gas, and the first electron discharge to which the tube is subjected will liberate a considerable amount of gas from the surface of the metal. To complete the evacuation to the required degree, the pump is maintained continuously operated while the tube is subjected to an electron discharge

* *Engineering*, 1913, vol. 96, p. 379.
† *Electrical Review*, 1917, vol. 80, p. 41.

between cathode and anode at a voltage which is gradually increased to a value somewhat greater than the normal working voltage of the valve. Care must be taken at the commencement of this operation not to use a voltage sufficient to cause the blue glow effect which will result in disintegration of the cathode; but towards the end of the operation the electronic bombardment of the anode must be very intense in order

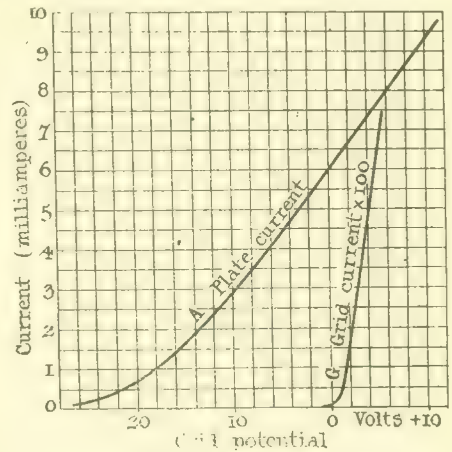


FIG. 14.

completely to free the metal electrodes from occluded gas.

By this means the bulb is exhausted down to a pressure of the order of 1/100,000 mm. of mercury, and no deterioration of this vacuum takes place during the normal operation of the valve.

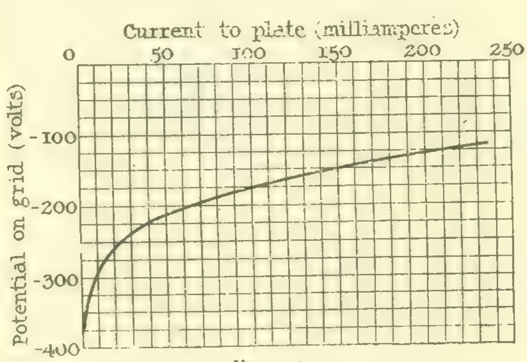


FIG. 14A.

As has been previously pointed out, the characteristics of this type of valve are perfectly smooth and regular, and quite free from all the disturbances and points of instability which often accompany the other types of gas-filled valves. The characteristics of the pliotron depend upon the length of filament used, the distance between filament and grid, the spacing between the grid wires, the diameter of the grid wires, the distance between grid and anode, and the size and shape of the

anode. The important characteristics of a pliotron to be observed are, first, the variation of the current flowing between the anode and cathode with the potential on the anode and with that on the grid; and second, the variation of the current flowing to the grid with the same potentials of anode and grid.

The characteristics of a pliotron of the type shown in Fig. 12 are shown in Fig. 14, the curves showing the variation of the current flowing to the plate and grid as the voltage on the grid is varied, while the anode potential is maintained constant at 220 volts. For different potentials applied to the anode, these curves are shifted vertically, by amounts proportional to the change in anode potential. Dr. Langmuir has found that these curves can be approximately represented by the formula

$$i = A\,(V_a + k\,V_g)^{3/2},$$

where i = current flowing to the anode,
V_a = voltage on the anode,
V_g = voltage on the grid.

and k and A constants which depend upon the dimensions of the valve and the relative shapes and positions of the electrodes.

In order to pass through the vacuum the currents at which this type of valve normally operates, the potentials which must be applied to the anode are considerably greater than those used in the case of the audion, but if it is necessary the pressure may be increased up to several thousand volts without any evidence of positive ionization such as the blue glow effect being observed.

Owing to the extensive commercial use of thermionic valves for various purposes at the present time, there is naturally considerable development and improvement continually going on, but it may safely be said that all the valves in use belong in principle to one or other of the types described above. A review by Dr. W. H. Eccles of the recent patents applied for on this class of apparatus, shows that the chief improvements which have been made are slight modifications in the arrangement of the electrodes and also alterations in the operating circuits to obtain increased sensitiveness.*

VI. The Use of the Thermionic Valve as a Rectifier, Amplifier, and as a Generator of Alternating Currents.

As it is not the object of the present paper to describe in detail the various circuit arrangements and their mode of operation, brief mention only will be made in conclusion of the more immediate applications of thermionic valves. For further details concerning the practical operation of these, reference may be made to some recent articles in the *Wireless World*,† and also to a paper read before the Institute of Radio Engineers by E. H. Armstrong in 1916.‡

The manner in which these valves may be used as detectors and rectifiers of electric oscillations for use in radio-telegraphic receiving stations, has already been described in connection with the Fleming valve and De Forest audion. The pliotron may be used in an exactly similar manner to the audion, except that if it is attempted to use a condenser in series with the grid as shown in Fig. 7 it will be found necessary to shunt the condenser with a high resistance and often to place a battery of a few volts' pressure in series with the resistance to prevent the accumulation of a large negative charge on the grid.

An interesting discovery was made by Mr. W. C. White of the General Electric Company's Research Laboratory, on the effect of a very minute trace of certain gases introduced into a pliotron valve which greatly increases the sensitiveness of the device as a detector.* To produce the desired pressure in the tube and maintain this constant, he used the vapour from a small quantity of silver amalgam placed in the tube. The quantity of gas in the tube is very much less than that in the audion and there is no evidence of positive gas ionization. In this condition, the characteristics of the tube show a kink, as in Fig. 15, indicating a region of instability for a certain value of the grid potential, and in this condition the sensitiveness of the detector is very high. The explanation of this phenomenon is rather obscure.

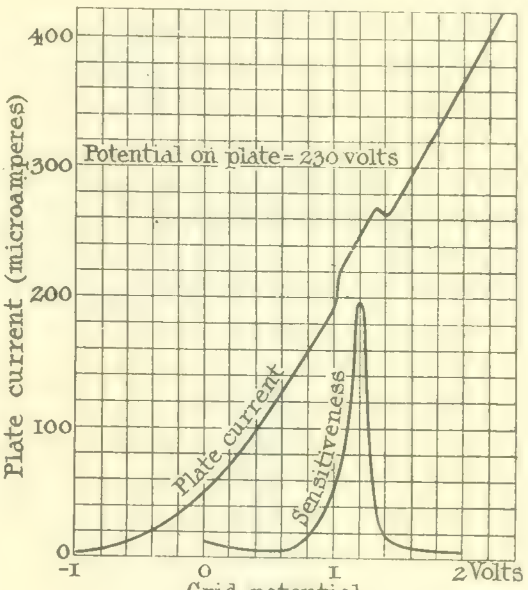


Fig. 15.

In 1916 an account was given by Mr G. S. Meikle, of the use of thermionic rectifiers for charging batteries at central stations.† For this purpose it is inconvenient to use the kenotron type of valve, owing to the

* W. H. Eccles: *Electrician*, 1916, vol. 77, pp. 571 and 594.
† *Wireless World*, 1917, vol. 5, pp. 158, 230, 236, 489, 594, 662.
‡ E. H. Armstrong: *Electrician*, 1916, vol. 76, p. 798.

* See footnotes on page 262.
† G. S. Meikle: *Electrical Review*, 1916, vol. 78, p. 472.

high voltages necessary for its operation. Consequently a gas-filled rectifier is used, and it was found in the course of its development that the introduction of pure argon into a kenotron tube at a pressure of from 3 to 8 cm. of mercury, while being quite effective in supplying positive ions to neutralize the space-charge effect, had no influence on the thermionic emission from the tungsten cathode and caused no serious disintegration of the latter. Valves on this principle may be designed to rectify currents of from a few milliamperes up to several amperes, at potentials of from two or three up to several thousand volts.

A further description of this commercial type of argon-filled rectifier, with a charging capacity of from 2 to 6 amperes, was given recently by R. E. Russell, who designates this valve by the term "Tungar Rectifier." *

The use of the three-electrode type of valve as an amplifier of the small electric oscillations occurring in

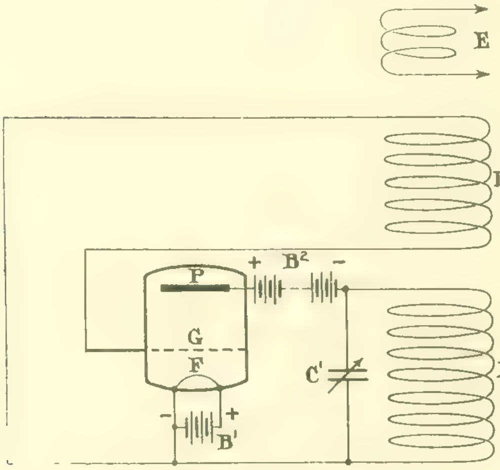


FIG. 16.

the receiving circuits of a radio-telegraph station were described above in the sections dealing with the audion and the Lieben-Reisz valve. This amplification may be carried out in either the radio-frequency or audio-frequency circuits or in both, as desired, since the operation of all the types of thermionic valves described is independent of the frequency of the currents used.

For this reason the valves may be employed for the amplification of speech currents in ordinary wire telephony, where it is desired to extend the range of speech transmission, or where the line is already so long that the attenuated currents are not sufficient to give an audible sound when the receiver is connected direct. In introducing an amplifier in this manner, the leads previously connected to the receiver are connected between the grid and the filament, the receiver being either transferred to the plate circuit or connected to the secondary of a transformer, the primary of which is connected in the plate circuit. Several valves may be connected in cascade as described in connection with the audion, in order to obtain increased amplification.

Thermionic-valve relays were used for the amplification of speech currents on this principle in the recent long-distance telephone tests between New York and San Francisco, a distance of 5,000 kilometres. Similar and more recent use of these valves as telephone relays on the line between Paris and Marseilles has shown that this application can effect a considerable saving in the amount of copper which must be used in the laying of trunk telephone lines.

The property of the three-electrode thermionic valve of amplifying small alternating currents enables it to be used as a generator of electric oscillations with but a slight modification of the circuit arrangements. Instead of the alternating potential being supplied from an external source, it is supplied from one winding, L_2, of a transformer, the other winding, L_1, of which is connected in the plate circuit as shown in Fig. 16.

If we apply a small oscillatory potential difference to the grid circuit, a magnified oscillation will result in the plate circuit. If the transformer connections are correct this increased current in the plate circuit will induce a further increased potential variation in the grid circuit. This will result in a further increased current in the plate circuit, and so the two circuits will continue to react on each other, and the amplitude of the oscillations in the plate circuit will continue to increase, until the whole system settles down to a steady state. By this means fairly powerful oscillations may be set up, depending upon the size of valve used, and by means of a third coil, E, coupled to the transformer, the generated alternating current may be tapped off and used for any purpose required.

The frequency of the oscillations is determined by the dimensions of the self-induction L_1 and capacity C_1 in the plate circuit, and by varying these the frequency may be altered within wide limits. Mr. W. C. White * has described experiments in which a pliotron was made to give oscillations at the extreme frequencies of one-half period per second, and 50 million periods per second.

The thermionic valve in this way provides a very convenient generator of perfectly steady, pure sine-wave alternating current, the frequency of which may be varied at will. The currents can be obtained of almost any desired amplitude by using a valve of suitable dimensions and characteristics. Pliotrons can be constructed with an output of 1 kilowatt, and greater powers than this can be easily obtained by connecting several of them in parallel. Used in this manner the thermionic valve would appear to provide an ideal generator of continuous oscillations for use in both radio-telegraphy and radio-telephony. In this application it is noteworthy to remark that some 300 to 500 of such oscillating valves were used in the successful long-distance wireless speech tests carried out in 1916 between Arlington, U.S.A., and the Eiffel Tower, and

* R. E. RUSSELL: *General Electric Review*, 1917, vol. 20, p. 209.

* W. C. WHITE: *General Electric Review*, 1916, vol. 19, p. 771.

between Arlington and Honolulu, a distance of 5,000 miles.*

The smaller form of the oscillating valve has also provided a very simple form of detector for use in continuous-wave radio-telegraphy on the heterodyne principle. The valve receiver is arranged to generate local oscillations of a frequency somewhere in the neighbourhood of those arising from the incoming signals. Those two frequencies, both too high to be audible themselves, are made to interfere, producing beats of a frequency equal to the difference of the two original frequencies, and audible in the telephone receiver as a musical note.

* P. R. COURSEY: *Wireless World*, 1916, vol. 4, p. 220.

ALTERNATORS OF RADIO FREQUENCY

Alfred N. Goldsmith

CHAPTER V.

(d) Alternators of Radio Frequency; Problem of Construction; Types of Solution; Goldschmidt Alternator; Frequency Multiplication by "Internal Reflection"; Constructional Details; Principle of Ferromagnetic Frequency Multiplier; Telefunken Company Frequency Doublers and Triplers; Arco Alternator of Telefunken Company; Alexanderson Alternator; Constructional Details; Electrical Characteristics; Experiments of Fessenden and National Electric Signaling Company; Experiments of General Electric Company; Alexanderson Triple Frequency Alternator.

(d) ALTERNATORS OF RADIO FREQUENCY.

As we have repeatedly seen, the first necessity in radio telephony is a steady stream of alternating current of radio frequency, available for modulation into speech form. We have treated in succession the arc, radio frequent spark, and vacuum tube generators of such currents (or first approximations to such currents). It would seem, at first sight, as if we had neglected deliberately an apparently far more natural and simple means of securing such currents and one well known to ordinary commercial electrical engineering. We refer, of course, to the normal alternator.

As a matter of fact, we have deferred the study of the radio frequency alternator because of the real difficulties in the direct generation of such very high frequency alternating currents. This will be seen if we consider the pitch or distance between adjacent armature windings for a 100,000-cycle alternator. If we assume the diameter of the rotor to be 2.0 feet (60 cm.) and a normal speed of rotation of 2,500 revolutions per minute, we find that the pole pitch has the extraordinarily small value of 0.016 inch (0.04 cm.), which is entirely impracticable when one considers that wire and insulation must all be crowded into the winding slot. In addition, there would have to be 4,800 poles.

It becomes necessary, then, if we persist in the process of direct generation of the current, to have a higher speed of rotation, since the pole

number must obviously be reduced. Suppose we choose the extremely high speed of rotation of 20,000 revolutions per minute. We shall need then 600 poles, and the width of winding becomes 0.12 inch (0.30 cm.) approximately. So close a winding can be accomplished if great care is exercised in the choice of wire insulation and in the milling out of the slots. The requirement of a speed of rotation of 20,000 revolutions per second makes a solid steel rotor and an alternator of the inductor type essential; and this is indeed the case for the radio frequency alternators of the present, which (with the exception of the Goldschmidt type, which must have a wound armature for electrical reasons) are all of the inductor type.

We shall see that there are thus at least three general lines of endeavor in connection with the generation of radio frequent currents by alternators. These are, firstly, the multiplication of frequency within the machine (Goldschmidt type); secondly, the multiplication of frequency outside the machine (*e. g.*, Arco alternator of the Telefunken Company, with frequency changers), and, thirdly, the direct generation in the machine of the frequency used (Alexanderson alternator of the General Electric Company). It is interesting to note that a solution of the problem of producing currents of frequencies of the order of 50,000 cycles per second (and wave-lengths of 6,000 meters) turns out to be

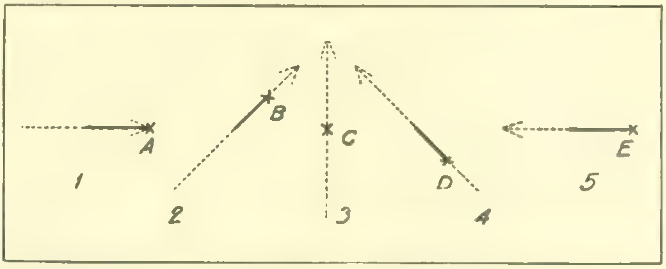


FIGURE 102—To-and-fro motion on rotating platform with equal periods of oscillation and rotation.

possible for considerable output powers (100 kilowatts or more) by all three methods. The details of these methods will be next considered.

Prior to the consideration in detail of the Goldschmidt radio frequency alternator and internal frequency changer, we desire to establish a principle of interest in connection therewith. This principle can be rendered clear from a simple analogy. Imagine a circular platform of moderate dimensions rotating once per minute, somewhat in the fashion of the carousels used in amusement resorts. Suppose, further, that the attendant elects to walk back and forth along a *diameter* of the rotating platform while it is in motion, and that he makes one to-and-fro trip in one minute, that is, in the same length of time as that required for one

complete rotation of the platform. It is required to find his path as viewed from an external stationary point, or, otherwise stated, with reference to the fixed ground under the platform.

Figure 102 shows a series of successive positions of the diametral line along which he walks, each position being 45 degrees further advanced than the preceding (that is, one-eighth revolution). The dotted line with the reference dotted arrow at one end indicates this diameter which, as will be seen, has reversed its direction in the half-revolution between positions 1 and 5. The position of the man on the diametral line is indicated in each case by the cross. It will be seen that the man never succeeds in getting to the left of the center of the platform because, as position 3 is passed, he comes to the reversed end of the diametral line, that is, the end away from the arrow.

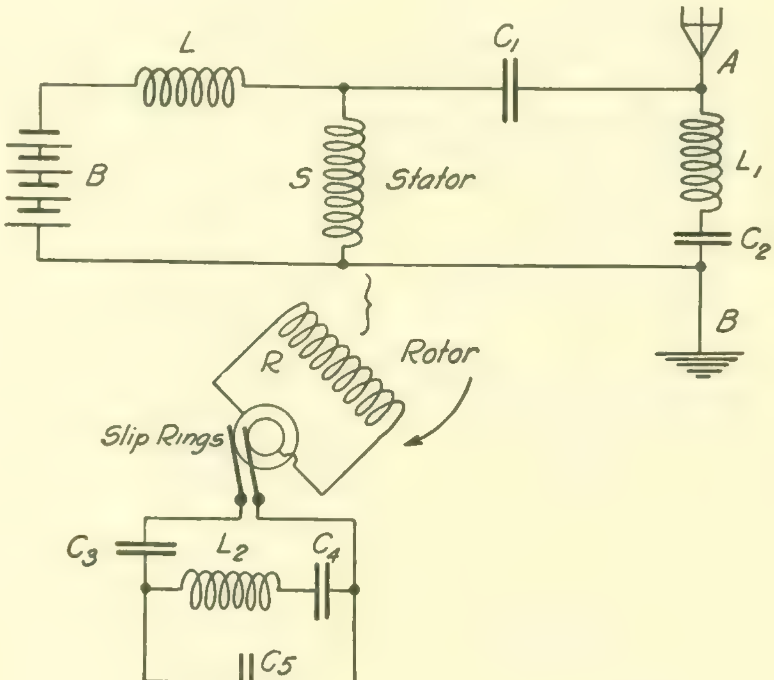


FIGURE 103—Winding of Goldschmidt alternator.

The important point is that the path of the man relative to the ground (that is, the curve $ABCDE$) is a closed curve, and that he has returned to his original position in a *half-revolution* of the platform. In other words, relative to the ground, he moves in a closed curve at twice the speed or double the frequency that the platform rotates.

We establish then the principle that an oscillatory movement of frequency n taking place on a system rotating with frequency n is equiva-

lent relative to fixed external points to an oscillation of half the amplitude or width of swing and of *double* frequency. The mathematical proof of this principle for simple harmonic (sinusoidal) vibrations is of the utmost simplicity, but need not here be given.

The diagrammatic wiring plan of the Goldschmidt alternator is given in Figure 103. The following description is based on an earlier explanation of this device by the Author. In the figure, the battery, B, supplies the direct current whereby the stator winding, S, becomes the field magnet of the alternator. L is a large inductance intended to prevent the flow of alternating currents through the battery circuit. In the field of the stator, S, is a rotor, R, which is short-circuited (that is, tuned to resonance) for the fundamental frequency produced when the rotor is revolved. The tuning of the rotor circuit is accomplished by means of the capacities, C_3 and C_4, and the inductance, L_2. It is to be noted that R and C_3 alone would be in resonance to the fundamental frequency, as also would L_2 and C_4. The complete circuit, $R\ C_3\ L_2\ C_4$, therefore contains approximately twice the inductance and half the capacity of either $R\ C_3$ or $L_2\ C_4$. Its period, therefore, is the same as that of either of these, and even if $L_2\ C_4$ were to be short-circuited, the rotor would still be resonant to the fundamental frequency. This permits shunting the condenser, C_5, across the circuit, $L_2\ C_4$, without disturbing the tuning. A perfectly similar arrangement is adopted for the stator by the use of the circuit, $S\ C_1\ L_1\ C_2$, except that the circuit in question is tuned to *twice* the fundamental frequency. It will be seen that as the rotor revolves in the field of the stator, powerful currents of the fundamental frequency will flow through it. The great magnitude of these currents is due to the fact that the rotor is itself part of a circuit resonant to the fundamental frequency. If we consider the field of the rotor, we see that it is a field produced by an alternating current of fundamental frequency n itself rotating with a frequency, n. Therefore, by the principle established at the beginning of this discussion, we may regard it as containing a component field of constant magnitude, but rotating with a doubled frequency, $2n$, relative to the stator. A further study of the phenomena would show that there was also present a constant field rotating with velocity 0. The rotor fields will therefore induce in the stator electromotive forces of twice the fundamental frequency (and zero frequency); and since a circuit resonant to the double frequency is provided, powerful currents of that frequency will flow through the stator. These alternating currents in the stator will induce in the rotor electromotive forces of frequencies, n, (from the steady field) and $3n$ (from the field of the current of frequency $2n$). By means of the condenser, C_5, a path resonant to the frequency, $3n$ is provided in the rotor. By

properly choosing the constants of the rotor circuits, the current of frequency n just mentioned can be made nearly to neutralise the current of frequency n first mentioned. The reason for this is that these currents can be brought to nearly complete opposition in phase and equal amplitude. There will be left then in the rotor a powerful current of triple frequency. Its field may be regarded, by a process of reasoning quite similar to that originally employed, as equivalent to two constant and equal rotating fields, revolving in opposite directions, with speeds of rotation corresponding to $2n$ and $4n$. There will, therefore, be induced in the stator currents of frequency $2n$ and $4n$. Of these, the current of frequency $2n$ will nearly completely neutralise the current of frequency $2n$ mentioned previously if the stator constants are properly chosen. The outstanding current of frequency $4n$ is shown in the figure as flowing into the capacity and inductance formed by the antenna, A, and the ground, B. We have, therefore, by "internal reflection" of energy, quadrupled the original frequency of the machine before using it for antenna excitation.

In the actual Goldschmidt installations (at Tuckerton, New Jersey, and Eilvese, Germany,) the motor drive of the alternator is accomplished by a 220-volt, direct current, 250-horse power motor having a speed of 4,000 R. P. M. For constant speed, a special form of sending key is used. This is shown in Figure 104. This key automatically inserts (by opening

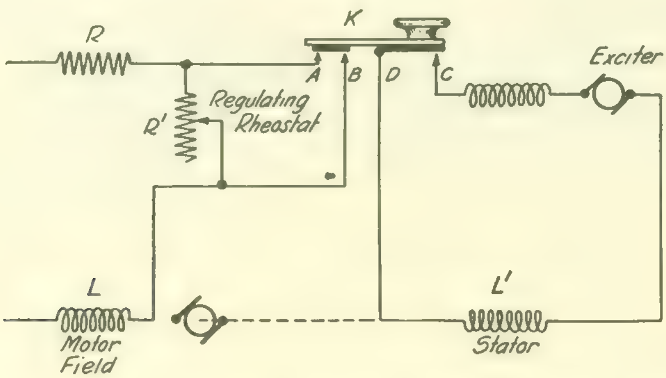


FIGURE 104—Goldschmidt alternator speed constancy system.

the back stop circuit) the resistance, R', in the motor field circuit just before the load is thrown on by closing the exciter circuit of the alternator (by the front contact of the key). In this way the motor tends to speed up just as load is thrown on, and the speed actually remains constant. In addition, the inertia of the heavy armature helps greatly.

The alternator itself is a 360-pole machine having a pole pitch or distance between windings of 7.5 mm. (0.3 inch), the slots in which the insulation and wire are placed being circular and of cross sectional

diameter of 5 mm. (0.2 inch). The rotor diameter is, therefore, about 90 cm. (3 feet) and the rotor weighs about 5 tons (4,500 kg.). The direct current power required for field excitation is about 5 per cent. the rated output of the machine.

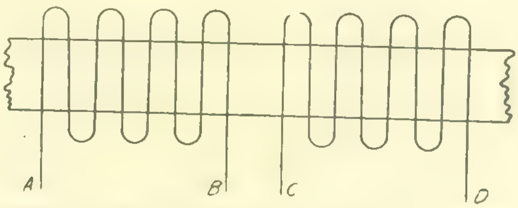


FIGURE 105—Portion of rotor or stator winding of Goldschmidt alternator (developed).

The winding of the machine is one conductor per pole, being a simple wave winding indicated in Figure 105. *AB* and *CD* are typical separate sections of the winding so arranged that they may be connected in series or parallel, depending on the electrical requirements. There are twenty-four such sections on the total circumference. Both rotor and stator are wound in the same way. The wire itself is very finely stranded, and made of number 40 Brown and Sharpe gauge* individual enamelled wires suitably twisted. The iron in the machine is very finely laminated, the sheets being only 0.05 mm. (0.002 inch) thick, insulated by paper between, 0.03 mm. (0.001 inch) thick. The rotor is more than one-third paper, which is a most unusual proportion. Such construction is particularly noteworthy in view of the high speed of peripheral rotation, namely 200 meters (600 feet) per second. The design of the brushes, bearing on the rotor slip rings, and the connection to these brushes required careful consideration, especially in view of the danger of burning the slip rings of any brush that was connected to an output circuit of greater or less impedance than any of the remaining circuits. In this connection, it must be mentioned that there were really more than one pair of slip ring connections to the rotor since a number of the rotor sections were placed in parallel outside the machine.

Some difficulty was experienced in preventing the currents which were generated from escaping to ground through the capacity (in air) between the conducting wires and the ground. In addition, there was always the danger that this air capacity would, in conjunction with the inductance of one or more of the machine windings, produce a circuit resonant to one of the frequencies generated, whereupon dangerously high voltages and currents would have arisen, and the output have disappeared.

*Diameter of number 40 wire=0.0031 inch=0.079 mm.

The accuracy of construction of such machines is extreme. Since the air gap clearance between rotor and stator is 0.8 mm. (about 0.03 inch), very accurate centering of the rotor was necessary. In addition, very strict parallelism of the armature and stator slots was required, a deviation from parallelism of one part in a thousand causing a fifth of the output of the machine to disappear!

One of the Goldschmidt alternators in use at Eilvese (Hanover, Germany), is shown in Figure 106. The machine is to the right, the

FIGURE 106—Goldschmidt alternator, motor, and reflection circuits at Eilvese, Germany.

driving motor to the left. The large brush surface chosen for the high-speed driving motor is significant. The condenser banks for tuning the various rotor and stator circuits are mounted on the walls, and are typical mica condensers. Some idea of the difficulty of leading the radio frequency currents into and out of the machine may be gained from the leads which are visible. The ingenious fashion in which the difficulties have been overcome is worthy of comment.

By January, 1917, two such alternators were being used in parallel when necessary, and put 275 amperes into the Eilvese antenna. Rapid telegraphy at a rate of 200 letters per minute has been accomplished by their use.

As has been previously stated, the second method of securing considerable amounts of sustained energy at radio frequencies when using alternators is that wherein an alternator of moderately high frequency is employed and the frequency is multiplied by external frequency changers and not, as in the Goldschmidt machine, by reflection of the energy in the machine itself. Most of the external frequency changers employed at the present time, particularly for considerable energy, are based on the properties of iron. Before explaining them in detail, it is desirable to quote from a paper by the Author on the subject of "Radio Frequency Changers."

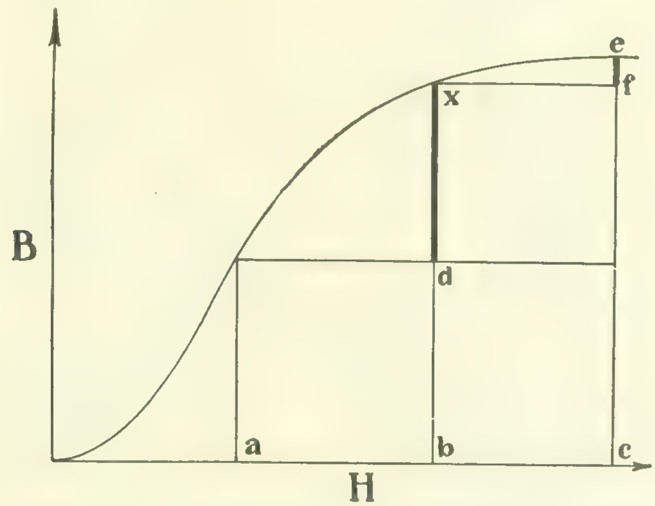


FIGURE 107—Magnetising force and magnetic induction curve for iron.

In Figure 107 is shown a typical *"B-H"* curve for iron. This is the curve which shows the connection between the magnetising force (e. g., expressed in ampere-turns or product of current flowing through the magnetising winding by the number of turns of winding) and resulting magnetisation or magnetic flux through the iron core (referred to as the "induction"). "Let us suppose that the magnetisation of the iron has been brought to the point, x. If now, by means of a superposed alternating magnetising force (such as may be produced by having around the iron core an auxiliary winding through which flows alternating current), equal increments and decrements be added to the magnetising force, the magnetic induction will increase during the positive half of the cycle by the small amount, ef. On the other hand, during the negative half of the cycle the induction will diminish by the considerably larger amount, xd. The explanation of this phenomenon is found in the well-known magnetic saturation qualities of iron, whence it results that for high magnetising forces the iron becomes saturated and the bend or

"knee" of the curve which is shown at x results. It will be seen, then, that though a sine-wave alternating current may be flowing through the auxiliary winding, the variation in the magnetic flux through the iron core will not be sinusoidal but distorted, the uppei halves of the curve being flattened. Such a deformation of the flux variation always occurs when nearly saturated iron cores are used under the conditions mentioned. However, such a deformation of a sine curve always leads to the production of upper harmonics (i. e., high frequencies in a secondary circuit wound around the same iron core), and it is upon this principle that the entire series of frequency changers employing iron is based."

An application of the principle just stated was shown by Epstein in 1902 (German patent 149,761) and has since been worked out and amplified in detail by Joly in 1910 and Vallauri in 1911. It is now extensively employed in various forms by the Telefunken Company under the patents of Count von Arco and Dr. A. Meissner. The circuit arrangement in a simple form is shown in Figure 108. As will be seen, an

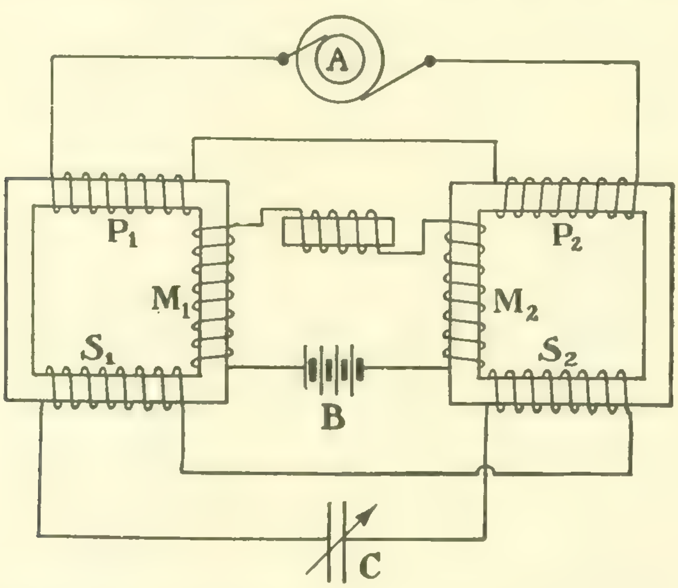


FIGURE 108—Telefunken Company frequency doubler.

alternating current source, A, sends its current through the primaries, P_1 and P_2, of each of two transformers having iron cores. These primaries may be connected in series or in parallel according to the secondary voltage and primary current which may be desired. They are wound oppositely relative to each other. A direct current source, B, e. g., a storage battery or small direct current generator, supplies the two auxiliary coils, M_1 and M_2, which coils are also wound on the same transformer cores. The direct current coils are wound oppositely. The sec-

ondaries of the two transformers, S_1 and S_2, are wound in the same direction, and connected as indicated in the figure.

The operation of the device is in the main as follows: The direct current flowing through M_1 and M_2 is so chosen that the iron is brought to the knee of the magnetisation curve, i. e., the point, x, in Figure 107. In consequence, during half the alternating current cycle, each of the transformers has a flattened addition to its iron magnetisation due to the iron saturation, while during the other half of the cycle it has a peaked diminution in its iron magnetisation due to the rapid drop of the iron curve below the point, x.

This effect is shown graphically in Figure 109. In curve a of the

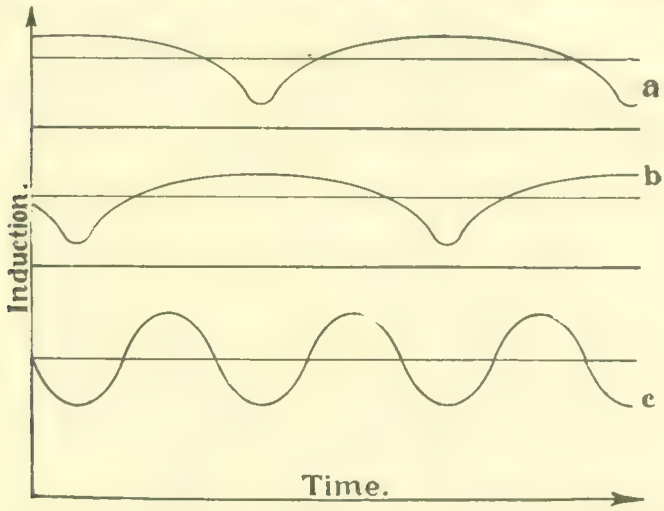


FIGURE 109—Iron magnetisation curves for frequency doublers.

figure, the fine horizontal line represents the constant magnetisation produced by the direct current which flows continuously. The curved line shows the actual magnetisation which results when the alternating current also flows in the winding, P_1. It will be seen that during the positive half of the alternating current cycle, there is only a small increase in the iron magnetisation, whereas during the negative half cycle, there is a large diminution in the iron magnetisation. It will further be noticed that the direct current coils and the alternating current coils on the two transformers are wound so that during the positive half cycle they assist each other on one transformer and that they simultaneously oppose each other on the other transformer. From this it follows that the induction in the second transformer is given by curve b, which lags practically a half cycle behind curve a. The resulting total magnetisation is given by curve c and is seen to contain a double frequency. Oscillograms of the voltages induced at the secondary terminals of each of the transformers are represented in Figure 110. The voltage at the terminal of one of

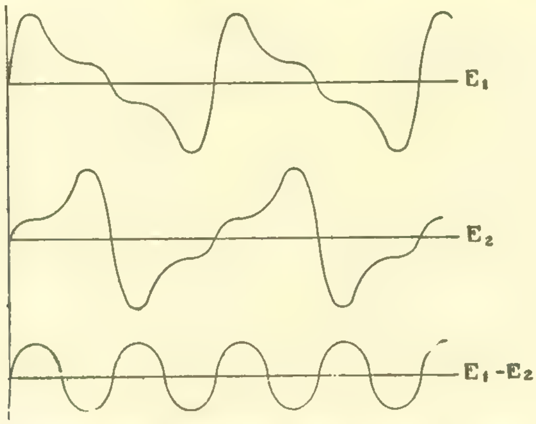


FIGURE 110—Induced voltages in secondarys of Telefunken Company frequency doubler.

the transformers is given by the curve E_1; that at the terminals of the secondary of the other transformer by E_2, and there is also shown the resultant voltage, namely E_1-E_2. The voltage curves are easily explicable on the ground that the voltage magnitude is proportional to the rate of change of the primary current so that it is only at times when the

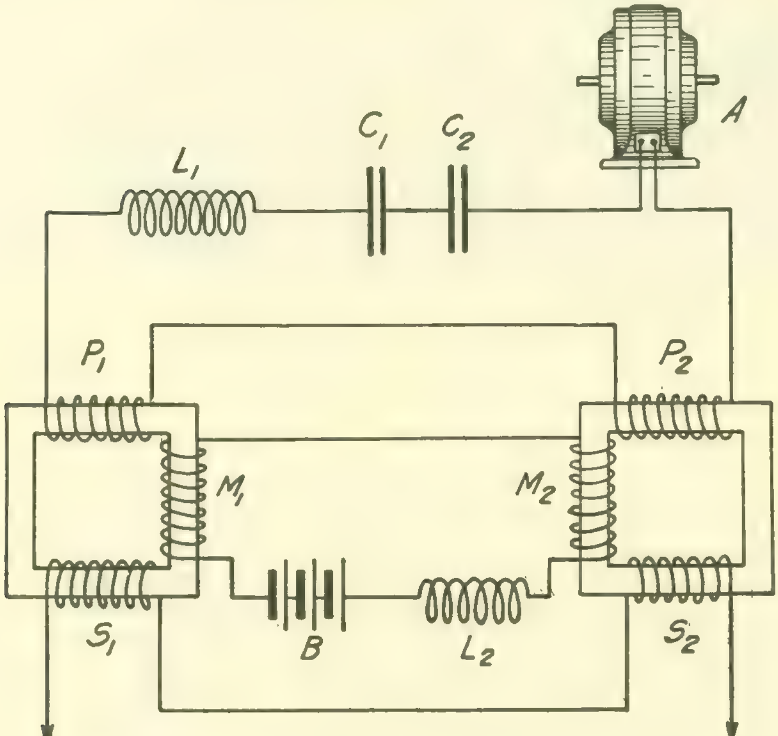


FIGURE 111—Frequency doublers used in actual practice.

primary current is changing from the flat portion to the peaked portion that the large secondary voltages are induced. The resultant voltage is seen to be of "double frequency." Its purity of wave is exaggerated in the figure.

Of course, the phenomena shown are for the frequency doubler with no load on the secondary, and these are to some degree modified when the double frequency energy is withdrawn. However, by secondary tuning and appropriate design, the same results as outlined can be obtained. A more detailed diagram, showing something of the actual practice with the frequency doublers, is given in Figure 111. It will be noted that the primary circuit of the alternator A is tuned by the inductances L_1, P_1, and P_2 and by the condensers C_1 and C_2. It will also be seen that there is a choke coil L_2 inserted in the direct current magnetising circuit of the frequency changers to prevent injuriously large radio frequency currents from being induced in this circuit.

It can further be shown, both theoretically and practically, that if the secondaries of the frequency changer, S_1 and S_2 are connected assisting instead of opposing each other, there will be produced in the secondary circuit an electromotive force of *triple* frequency. Thus the same equipment can be readily used either as a doubler or a tripler.

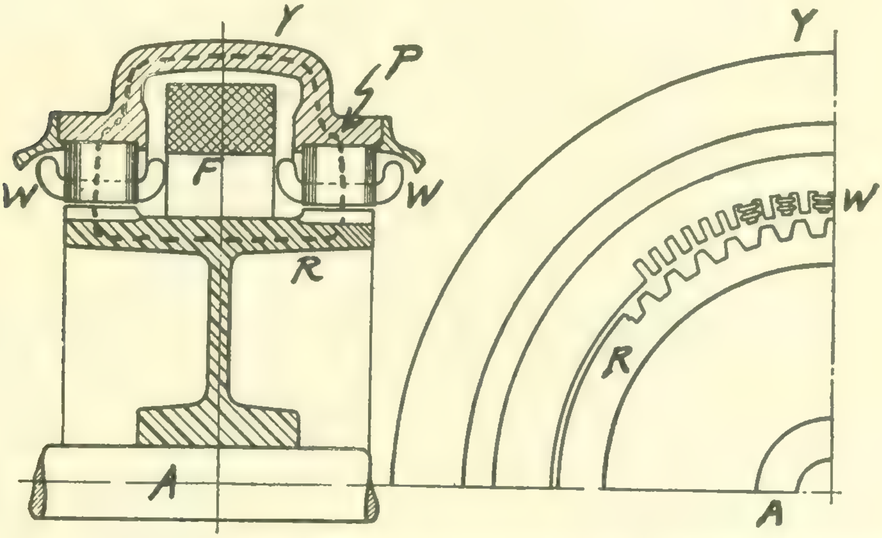


FIGURE 112—General arrangement of Telefunken radio frequency alternator.

A clear idea of the interior construction of the Telefunken radio frequency alternators can be obtained from Figure 112. The left hand portion of the figure gives a vertical cross section of half of the machine. Here A is the shaft to which the driving motor or engine is attached either directly or through appropriate gearing. R is the inductor or

rotor, a rotating mass of steel, on the outer surface of which are cut a great number of grooves parallel to A thus producing the longitudinal teeth and slots indicated in cross section at R in the right hand portion of the figure. The constant direct current passing through the field winding, F (which is an ordinary circular coil or ring of square cross section), produces a field the lines of force of which take the path indicated by the dashed line, P. It will be seen that this path is suitably interlinked with the coil, F, and passes through the yoke, Y, the stator slot supports W, and the rotor, R. The armature, which is in two portions, one on each

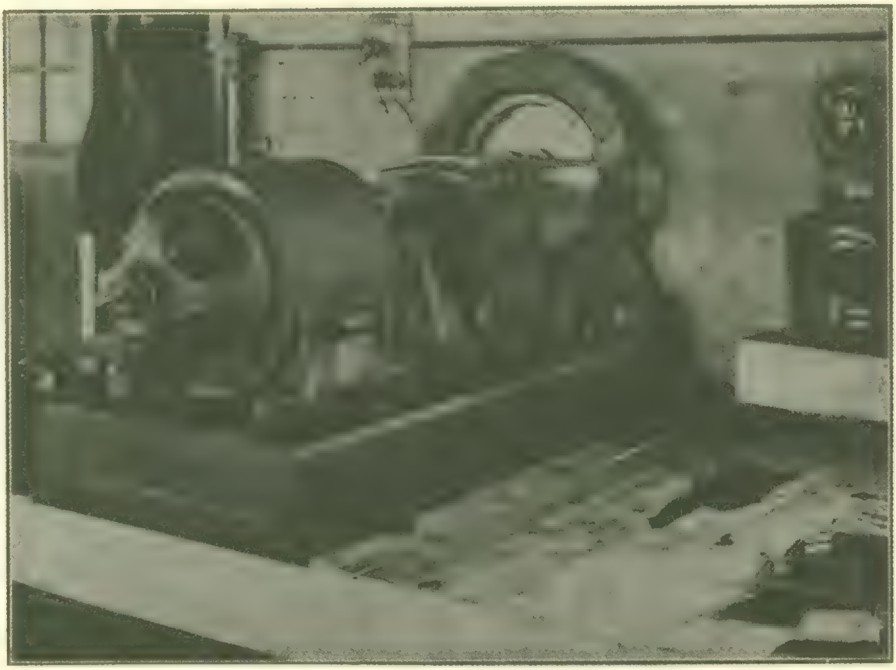


FIGURE 113—Telefunken Company 10 K. W., 10,000 cycle alternator.

side of the field coil consists of to-and-fro windings in longitudinal slots parallel to those of the rotor. The portions of the armature can be placed in series or parallel in accordance with the characteristics of the circuit to which the machine is connected. The mode of winding the armature is indicated at W in the right hand portion of the figure. It is evident that as the rotor revolves, the field passing through the armature turns, W pulsates back and forth with a frequency corresponding to the product of the number of rotor slots and the rotor revolutions per second. The advantage of this (inductor) type of machine as compared to those with

wound armatures is that the rotating portion consists of a solid steel mass and is consequently much more sturdy than a normal armature carrying wire windings on a laminated support.

The appearance of a small (10 K. W.) machine of this type is indicated in Figure 113. The motor is mounted at the front of the base plate and the alternator at the rear. The housing between them contains the multiplying gear. The motor starter, and the speed controlling rheostat are mounted on the wall at the rear. The machine shown produced 10,000 cycles per second directly. Its use in radio telephony, together with the

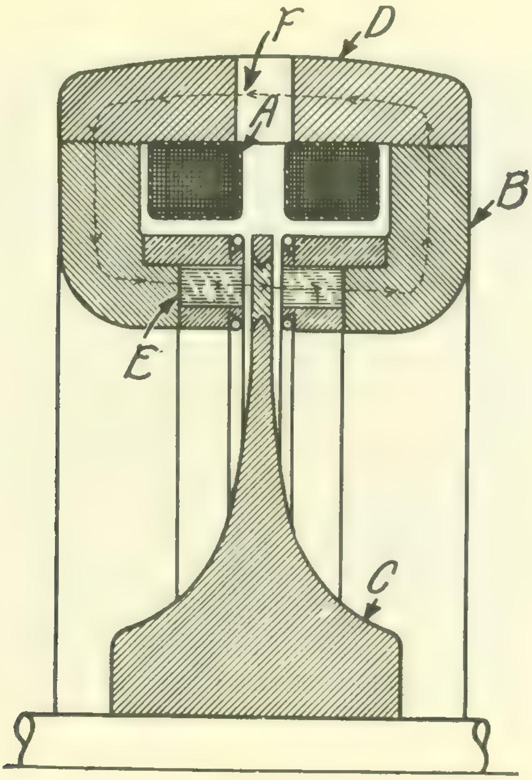


FIGURE 114—General Electric Company—Alexanderson alternator.

other portions of a frequency changer set of which it was a part, will be described under "Control Systems," on page 190.

Continuing our consideration of the generation of radio frequency currents by alternators, we pass to an interesting and important form of alternator largely developed by Mr. E. F. W. Alexanderson of the General Electric Company. This machine has generally been distinguished by the direct generation of the very high frequency desired, and its construction has given rise to numerous difficult problems. The experimental work in connection with these alternators was originally undertaken by the Gen-

eral Electric Company at the suggestion of Mr. R. A. Fessenden, then associated with the National Electric Signaling Company; and much of the earlier development was done in conjunction with that company.

In 1908, Mr. Alexanderson described a 100,000 cycle alternator of this type, built to deliver approximately 2 kilowatts. A later description given by him follows (with brief additions by the Author):

"The alternator is of the inductor type (that is, with stationary armature and field, but with a rotating element which causes a pulsating field to cut the armature conductors), and is provided with a novel arrangement of the magnetic circuit, allowing the construction of a rotor which can be operated at exceedingly high speeds. In the final form of the alternators, shown in Figure 114, the rotor, *C*, consists of a steel disc with a thin rim and much thicker hub, shaped for maximum strength

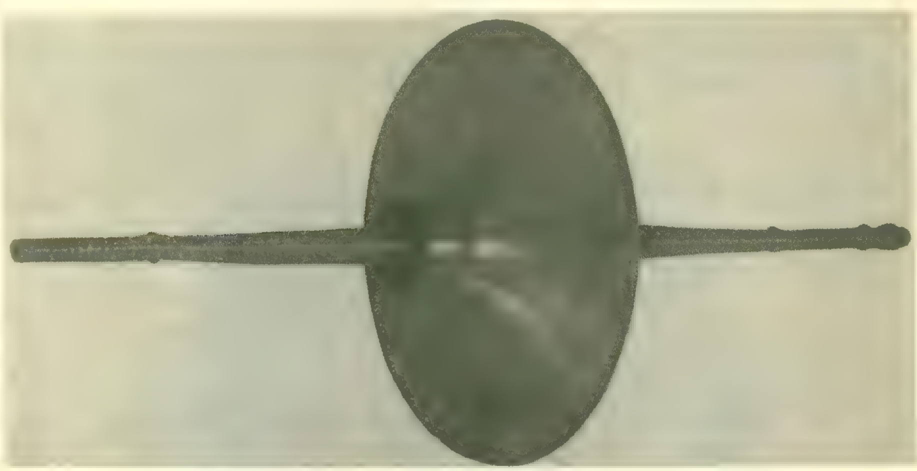


FIGURE 115—Rotor and shaft of 100,000 cycle Alexanderson alternator.

(that is, with a width that progressively diminishes from the shaft out, so that the outward strain on the material because of centrifugal force is the same from the shaft to outer rim). The field excitation is provided by two coils, *A*, located concentric with the disc and creating a magnetic field the lines of force, *F*, of which pass through the cast iron frame, *D*, the laminated armature support, *B* and *E*, with its teeth, and the disc, *C*. This flux also passes through the narrow air gaps on each side of the disc rotor, and is indicated in the figure by the dashed line with arrows. *B* represents the two armatures which are secured in the frame by means of a thread, in order to allow an adjustment of the airgap, the laminations carrying the armature conductors being located at *E*. Instead of poles or teeth, the disc, *C*, is provided with slots which are milled through the thin rim so as to leave spokes of steel between the

slots. The slots are filled with a non-magnetic material (phosphor bronze) which is riveted in place solidly, in order to stand the centrifugal force and to provide a smooth surface on the disc so as to reduce air friction. The centrifugal force on each slot filler is no less than eighty pounds (37 kg.) at the high speed at which the machine is run.

"The standard 100,000 cycle rotor of chrome nickel steel with 300 slots is shown in Figure 115." The shaft bearings are clearly visible at the ends, and it will be seen that they are arranged so as to make forced oiling practicable. The shaft in this type of alternator is long and flexible, thus permitting the rotor to center itself and rotate about its center of mass somewhat as is done in the case of centrifugal dryers for laundries. In this way, excessive shaft strains are avoided. There are certain speeds (1,700 and 9,000 R. P. M.) for which the shaft and rotor pass through their own resonant periods of mechanical vibration, and at these speeds marked shaft vibration tends to occur.

A closer view of a portion of the rotor, showing the slot fillers of non-magnetic material, is given in Figure 116. Some idea of the care

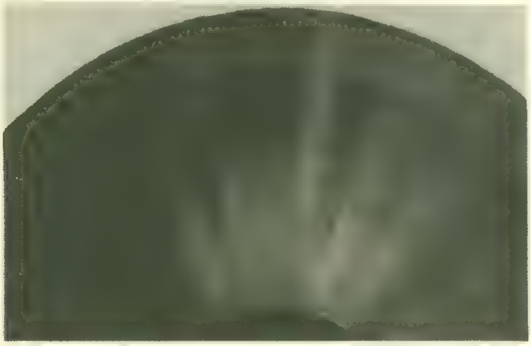


FIGURE 116—Portion of rotor of Alexanderson 100,000 cycle alternator, showing slots in disc.

required in the construction of such a machine can be gained from the details of the rotor construction. Since the speed of rotation of the rotor is 20,000 revolutions per minute, or over 330 revolutions per second, the actual speed at the rim is nearly twelve miles per minute! Such a machine must, accordingly, be considered a masterpiece of engineering design. (A whimsical calculation has been made which shows that the rotor, if released while spinning at full speed, would, if it maintained its speed thereafter, roll from America to Europe in a few hours!)

There are two methods of armature winding employed in the simpler forms of these machines. The first form, which is a simple to-and-fro

winding (one turn per slot) is shown in Figure 117. In this form of armature there are 600 slots for a 100,000 cycle machine. A second form of winding for the armature has only 400 slots for the 100,000 cycle machine. It is shown in Figure 118, and really consists of two windings

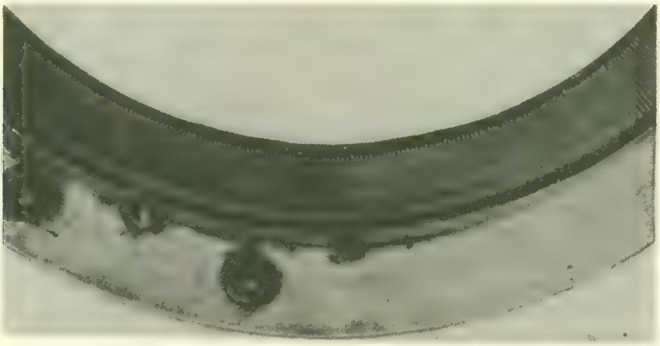


Figure 117—Portion of armature winding of 100,000 cycle Alexanderson alternator; 600-slot type.

in parallel in each of which, by a sort of vernier action, a 300-slot rotor field produces 100,000 cycle current in the same phase in each of the armature windings. *It is possible, using an 800-slot armature winding of the last-mentioned type, to produce a 200,000 cycle current by direct*

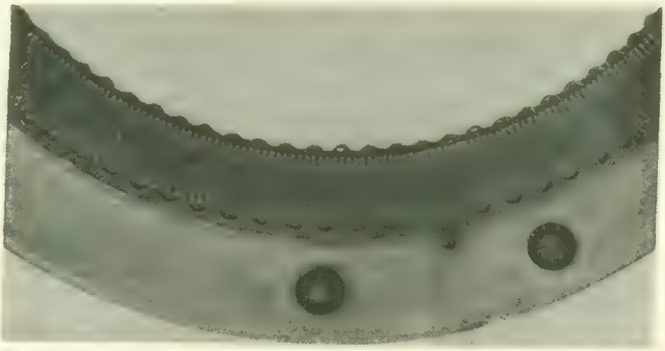


Figure 118—Portion of armature winding of 100,000 cycle Alexanderson alternator; 400-slot type.

generation. This is by far the highest frequency which has as yet been produced directly by an alternator.

Through the courtesy of John L. Hogan, Jr., of the National Electric Signaling Company, we are enabled to show in Figure 119 a test of an early form of 80,000 cycle alternator built by the General Electric Company and used at the Brant Rock station of the National Electric Signaling Company in 1906. This machine had a double inductor with inward

projecting teeth on each half, and the stator lay between the two "saucer" shaped inductors. It will be seen that this machine was belt driven to get the proper ratio of motor to alternator speeds, and that the motor is much larger than the alternator. This is quite explicable when it is remembered that the windage loss in these machines at 20,000 R. P. M. is high, it having been claimed that the rotor is actually polished either by air friction or by the friction of floating dust particles. In any case, the

Figure 119—Early form of Alexanderson alternator under test at Brant Rock Station of National Electric Signaling Company.

air streaming out from the machine is appreciably warmed. This windage loss becomes important in any but the smallest alternators of this type.

A somewhat similar machine built by the National Electric Signaling Company in 1907 and equipped with de Laval steam turbine drive is shown in Figure 120. This has the advantage that, since the turbine is itself an extremely high speed machine, the gearing losses are eliminated by the direct drive. Sufficiently accurate speed regulation of a steam

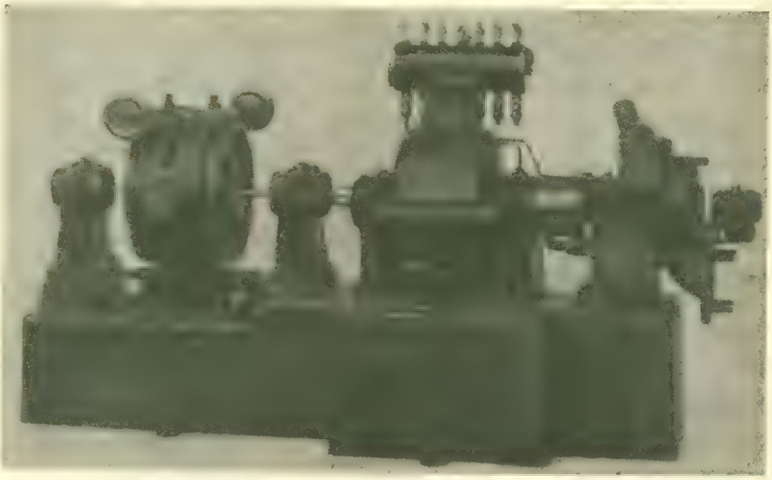


FIGURE 120—Early form of Alexanderson alternator coupled to de Laval turbine; under test by National Electric Signaling Company.

driven machine is secured in practice by maintaining the steam pressure and radio frequency load at constant values. The gearing shown in the figure is used to reduce the main shaft speed in the ratio of 1-to-10 for the operation of the turbine governor. It will be noted that the alternator in this figure has an adjustment to rotate each armature slightly relative to the frame so as to bring the generated currents into phase and also has an adjustment whereby, as stated previously, the armatures may be brought nearer to or further from the rotor for precise adjustment of the air gap. Such an adjustment is of importance since the output of

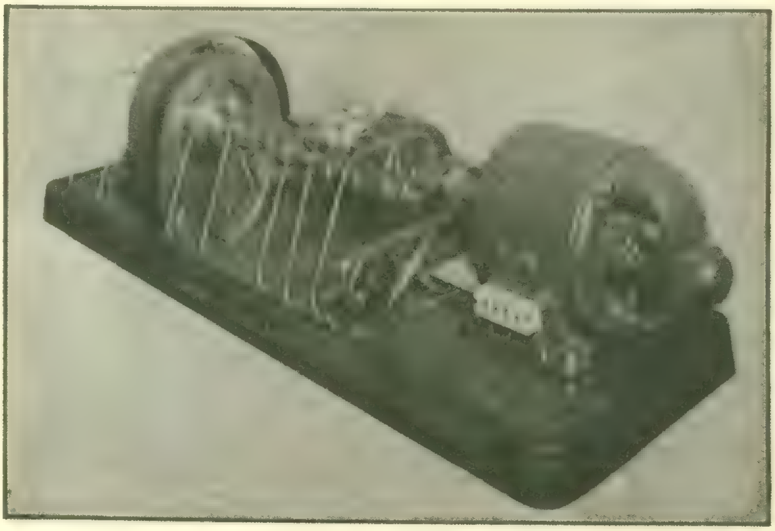


FIGURE 121—Intermediate type of Alexanderson alternator.

the machine is largely dependent on the air gap, and a very small air gap (of 5 or 10 thousandths of an inch, or an eighth to a quarter of a millimeter) is of advantage. The usual gap is 0.015 inch (0.38 mm.) with a generated voltage of 150, although voltages as high as 300 can be obtained with a 0.004 inch gap.

This machine was in almost daily use at Brant Rock for several years, and ran for hours at a time without attention. The maximum output was something over 1 K. W. at 100,000 cycles.

A later form of a 2 K. W. Alexanderson alternator is shown in Figure 121. This set shows the elaborate forced-feed oiling system which has been adopted for the later machines. The auxiliary and main bearings to the right of the rotor are clearly visible.

The most recent form of 2 K. W. machine of this type is shown in Figure 122. The oiling system in this machine is provided with an inter-

FIGURE 122—Recent type of 2 K.V.A., 100,000 cycle Alexanderson alternator.

esting protective device. The oil which is returned to the reservoir at the right of the base plate (the tank having a sheet metal cover with handle) strikes a small pivoted shovel. Its weight depresses this shovel against a controlling spring tension. Should the flow of oil cease for any reason, the shovel flies up and automatically opens the driving motor circuits. In this way, any danger of unoiled bearings "freezing" is obviated. In this set, the alternator is driven by a 110 or 220-volt, direct current, shunt motor with commutating poles. The motor speed is 2,000 revolutions per minute and this is raised to the requisite 20,000 revolutions per minute by the 1-to-10 helical-cut gearing enclosed in the housing at the center of the base. The oil pump, which is chain driven from the motor shaft, is shown at the right hand corner of the base. To prevent any possibility of binding between the two thrust bearings, due to expansion of the shaft because of heating, the machine is provided with a

system of equalizing levers to compensate for such shaft heating. These levers are shown in the left front of Figure 122 with the elastic controlling leaf between them. Any tendency which would cause a change in air gap is counteracted by the automatic action of the levers. If the air gap should tend to change at either side, the magnetic attraction at that side would cause an additional pressure and consequent heating on the thrust bearings at that end; and a consequent expansion of the shaft there would bring the rotating disc back to a central position.

The expansion of the shaft by temperature is thus taken advantage of to insure a correct alignment. The usual output of these alternators is from 10 amperes at 200 volts to 20 amperes at 100 volts, depending on the nature of the load and the mode of internal connection of the armature sections of the machine. The effective resistance of the armature is 1.2 ohms, the inductance being 8.6 microhenrys corresponding to 5.4 ohms, at a frequency of 100,000 cycles, or wave length of 3,000 meters. The resonance condenser load would, therefore, be 0.29 microfarad at the frequency mentioned, if no loading coil were used external to the machine.

Another recent type of Alexanderson radio frequency alternator is the so-called "gyro alternator." The designation is based on the similarity of bearings in the machine in question and those in a high speed gyroscopic compass. A heavy shaft is used, so that vibration at the "critical speeds" does not occur, these speeds being much higher than those at which the machine is actually run. The use of ball bearings in this machine has simplified the construction. No auxiliary bearings are needed in this machine.

FIGURE 123—Recent General Electric Company-Alexanderson alternator of "gyro" type.

Figure 123 shows one of these machines with belted driving motor and all auxiliaries needed for a complete radiophone equipment mounted on a base. The particular equipment shown has been used under favorable conditions for the transmission of speech 160 miles (250 km.), between Schenectady and the Author's laboratory in New York. The alternator generates 33,000 cycles per second, which is transformed into 100,000 cycles (corresponding to a wave length of 3,000 m.). The 100,000 cycle energy is modulated by a magnetic amplifier which is controlled directly by a standard microphone. A description of the magnetic amplifier system of modulation follows under "Modulation Control Systems," page 195.

Passing from the smaller machines, Mr. Alexanderson has had built a 50 kilowatt, 50,000 cycle alternator (and very considerably larger machines are under test and construction). This machine is shown in Figure 124. The open circuit voltage of this machine and the trans-

FIGURE 124—50 kilowatt, 50,000 cycle, General Electric Company-Alexanderson alternator.

former described below is about 550 volts, but the machine is normally operated at about 125 amperes and 400 volts. The rotor is similar to, although naturally larger than that of the smaller machines previously described, but an extremely heavy and rigid shaft is used. The machine has proven capable of furnishing 85 kilowatts for brief periods. Operating at 3,500 revolutions per minute, its bearings and shaft construction are similar to those of normal high speed turbines. The machine speed never attains the "critical speed" value, thus avoiding the necessity for auxiliary bearings. Because of the very rigid shaft, the rotor is not measurably deflected by the magnetic field. "The thrust bearings for

the collars shown at each end of the rotor shaft are held in position with a system of equalizers, which have for their object the avoidance of any possibility of binding in the bearings due to expansion of the shaft from change in temperature, and at the same time automatically draw up all slack in the bearings as they become worn. The equalizers are the heavy vertical columns and links shown in the photograph of the assembled machine.

"The direct generation of radio frequencies by a machine working on the principle of a simple alternator is possible only by the use of a very low voltage winding. On the other hand, if the alternator windings were designed to be connected directly in series with an antenna, the terminal voltage would be about 2,000 to 3,000 volts. Thus it is apparent that with this type of machine it is necessary to use a transformer between the machine and its output circuit. The alternator windings consist of thirty-two independent circuits connected to the same number of independent primaries of the transformer. The transformer has a number of secondary circuits which can be connected for various ratios of transformation between 4-to-1 and 24-to-1. Thus the alternator can be adapted to antennas of greatly different characteristics. The primary windings of the transformer are grounded in the middle, so that the greatest potential difference to ground on the alternator winding is one-half the voltage generated by one alternator circuit.

"The transformer is a closely coupled one, the coupling coefficient being 0.95. In the phraseology of the alternating current designers, the transformer may be described as having about 30 per cent. magnetizing current and 30 per cent. total leakage. Although the transformer has no iron core, it has a measurable core loss due to the eddy currents in the conductors caused by the magnetic flux. If it were not for these eddy currents, the efficiency of the transformer would be close to 99 per cent.; as it is, the efficiency is about 95 per cent. This efficiency is approximately constant between frequencies of 25,000 and 50,000 cycles, because what the transformer in one sense gains by the higher frequency, it loses on account of the higher eddy current accompanying that frequency. The numerous multiple circuits in the primary, as well as those in the secondary, are carefully transposed so as to make cross currents impossible between the different circuits.

"While it appears that the most practical arrangement from all points of view is the one described, *i. e.*, a low voltage winding and transformer, experiments have been made with windings distributed in such a way that larger slots can be used with room for more insulation. A sample machine of this type of 3 k.w. output at 45,000 cycles was built, and a diagrammatic representation of the armature cross section and rotor is given in Figure 125. This generates a frequency three times as high as

the one for which the slots on the winding are apparently designed. This method may be characterized as generating triple harmonics without the fundamental. The action is somewhat like that of a vernier, the flux through the stator projections changing from that due to two teeth on the rotor to that due to one tooth at three times the apparent frequency of the machine. While the characteristics of this machine have proven entirely satisfactory, in accordance with expectations, it is probable that the original simple form of winding will be adhered to, because the concentration of large conductors with more current in one slot causes not only higher losses, but also a lower rate of heat dissipation and therefore less output can be expected from the same amount of material."

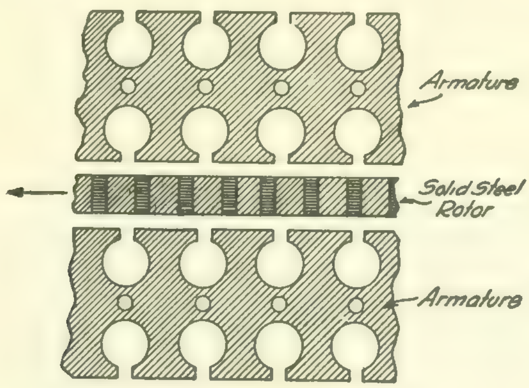


Figure 125—Diagrammatic representation of Alexanderson alternator for direct generator of triple frequency.

It may here be mentioned that the machines shown in Figures 121, 122, 123, and 124 have all been used for radio telephony in connection with further devices which will be described under "Control Systems." The first was used principally by the National Electric Signaling Company in Mr. Fessenden's tests between Boston and New York (Jamaica), a distance of some 150 miles (240 km.). This was, however, not a matter of regular communication, but rather of test work. The machine shown in Figure 122 has enabled quite regular communication between Schenectady and New York, the distance being 150 miles (250 km.). Even the smallest machine (of Figure 123) running on much reduced power, has enabled the same stretch to be bridged when suitable receiving apparatus was employed.

With the large machine shown in Figure 124, employing the magnetic amplifier controlling device to be described hereafter, the output was successfully modulated between 5.8 kilowatts minimum and 42.7 kilowatts maximum. This is, to date, the maximum amount of radio frequency energy controlled telephonically by any means.

WIRELESS POSSIBILITIES

A[rthur] R. Burrows

WIRELESS POSSIBILITIES

Speculations upon the Future of Radiotelegraphy and Allied Developments: The Forthcoming Demand in Anglo-Saxon Countries for Specialists in this Rapidly Widening Field of Activity.

By A. R. Burrows.

MANY mysterious happenings in this great world contest of force and ingenuity have been credited to "wireless." Proud warships, manned by the bravest and sturdiest seamen the world has known, and equipped with the finest products of modern engineering, have gone sky-high in a cloud of fragments when lying peacefully at anchor; wonderful airships (revealing great skill in design and delicacy of structure), which years of practical experience have shown to be capable of riding buoyantly even in the rarer airs of higher altitudes, have fallen ignominiously to earth, mere tangled heaps of metal and machinery at the moment when they were expected to fulfil the hopes which had been placed in them.

After all such "ups and downs," the word "wireless" has been whispered abroad as the mysterious agent of destruction, and, although certain wise restrictions forbid discussion upon the extent to which such interpretations are justified, the credence attached to such suggestions indicates very clearly a certain inherent faith in the possibilities surrounding etheric phenomena.

In several secret services forming essential parts of the modern war machine wireless undoubtedly has an important place. It has worked, and continues to work, unobtrusively, and in many instances has fully justified its application. Occasionally a peep behind the scenes is afforded through some ephemeral departmental *communiqué*, but otherwise strict silence has to be preserved.

Being deprived, therefore, once again of a most fascinating subject for discussion, some thoughts may be given to that keenly anticipated and highly problematical era—after the war. What can "wireless" do to repair the havoc wrought by the present unprecedented struggle? Have any discoveries been made since that fateful August of 1914 which suggest new spheres for "wireless" activity? What of the much-heralded Wireless Age?

. . . .

The whole realm of nature is under wireless control. This fact, expressed in all reverence, is a natural source of optimism to all engaged in radio research, and strengthens the belief, claiming fresh adherents daily, that radiotelegraphy, which even now is still in its infancy, lies but on the fringe of a vast field of discovery. Viewed in the same light, one sees in the pioneer researches of Hertz and Marconi, not so much subjects for wonderment, as indications of man's closer understanding of the great natural forces.

Wireless, of course, makes unusual claims upon the imagination. Although on the one hand the wireless control exercised by the sun at a distance of some ninety odd millions of miles produces very perceptible

effects upon our personal comfort and the growth of vegetation, the etheric waves generated artificially to date for the conveyance of Morse signals over the relatively small terrestrial intervals of apparent space affect none of our known senses. For well over a decade incessant groups of vibrations, constituting recognisable signals, have been radiated from all parts of Europe, and have been passing through the bodies of each one of us, yet their presence has not been felt, and few outside the world of radiotelegraphic research have even thought of their existence.

Bearing in mind the natural transmission of light, heat, and energy over such vast distances as astronomical calculations have revealed, no excuse appears necessary for the suggestion that most startling discoveries and surprising applications of wireless control may be expected in time. Each new development suggests that if it is wise to use common sense in discriminating between the probable, possible, and extremely unlikely, in connection with affairs attributed to "wireless," consistent scepticism is equally inadvisable. The brief history of wireless telegraphy already teaches one that scepticism, even from those possessing the most intimate knowledge of scientific principles, is a dangerous enemy to progress.

One of the most interesting possessions of Marconi's Wireless Telegraph Company is a collection of Press cuttings dating from the time of Mr. Marconi's arrival in England. In view of the present position of radiotelegraphy, many of these cuttings read like extracts from comic journals, and not the serious expressions of weighty organs of public opinion. Nothing could demonstrate more clearly the ease with which dispassionate thought can be disturbed and how powerful are the human frailties which serve to retard evolution.

Mr. Marconi had no sooner arrived in England than the whole machinery of obstruction was put into action. As scouts before the hostile army, there appeared a group of scientists, amongst them men of considerable attainments, who opened the attack by claiming priority for their own ideas. Others, including men of recognised prominence in the scientific world, contented themselves with disparaging the work of the newcomer, by repeating in public, wherever opportunity allowed, either that Marconi had made no scientific advance or that "what the Italian scientist had really done was to increase the distance . . . the basic facts having been known even to the ancients." Nowhere outside the little group that stood by Marconi during his early tests under Post Office observation is there evidence of support for the new development by scientific circles or the public. On the contrary, quite early in 1897 there were indications of underground activities by vested interests, which were more concerned with "damning with faint praise" than in seeing how far the new discoveries might be utilised to their benefit. The lay Press, which then seemed so inadequately equipped for dealing with scientific matters and frightened possibly by the attitude of English scientific opinion generally, left all initiative to its letter writers, but to its credit did not adopt the persistently hostile attitude of many technical papers.

That an almost complete paralysis of expression had been created by Mr. Marconi's surprising inventions is evidenced by the fact that some of the public organs which did enter into the realm of controversy

succeeded sooner or later in contradicting themselves. In 1897, for instance, the Post Office was being abused for spending public money in investigating "a young foreigner's" inventions to the neglect of home research; in 1900, when certain possibilities of "wireless" were beyond dispute, the same British Government was verbally castigated for having "fought shy" of the invention.

One factor which undoubtedly irritated and perplexed hostile interests, and actually formed the subject of hostile criticism in the technical Press, was Mr. Marconi's discreet silence. There is no doubt that certain of these organs had formed the opinion that young Marconi was a quack, and, having acquired this conviction, had expected him to push his wares in the manner common to that fraternity. But no such thing happened; and, whilst the critics of the new telegraphy were putting up what we can now describe as a barrage against public opinion, the young inventor tantalisingly went on quietly with his research. All efforts at discouragement were but as waves beating upon a rock. Well away from this hostile criticism, in the quiet retreat of Poole harbour and on craft sailing off the coasts of Hampshire and Dorset, Mr. Marconi was systematically engaged in piercing the veil surrounding etheric phenomena.

From time to time there would appear a terse paragraph showing that the range of wireless intercommunication was gradually increasing —one day an intervening distance of 12 miles had been spanned, in March, 1899, the English Channel had been bridged between Wimereux and the South Foreland Lighthouse, in July of the same year three British battleships managed to interchange messages at distances up to 74 nautical miles; so the magic circle spread in diameter.

By 1900 the critics were more or less resigned to the fact that radiotelegraphy in some form or another was certain to play a permanent part in marine intercommunication.

In February, 1901, a Liverpool journal referred to "wireless" as a "lusty and vigorous infant," and following the transmission of messages in the same month over the 200 miles separating St. Catherine's Point from the Lizard there was a pronounced burst of newspaper interest. An enterprising and somewhat daring reporter, however, who ventured to invite the opinion of the Director of a cable company upon the possibility of "wirelessing" from Britain to America, obtained the admission that there was no finality in things electrical, but that great difficulty could be foreseen in mooring ship relay stations at intervals across the Atlantic.

Here, perhaps, the sequence of events has been broken. Transatlantic "wireless" appears to have first caught public fancy in January, 1901, when, following the appearance of a paragraph in a London daily to the effect that the Marconi Company had purchased land at Mullion, in Cornwall, and were "maintaining such secrecy that even the former proprietor was not admitted to the premises," there instantly arose fantastic stories of Atlantic "cablegrams" at ½d. per word. Simultaneously there was opened a speculative controversy upon the prospects of establishing wireless communication with the Martians, a journalistic toboggan from the sublime to the ridiculous, and some budding mathematician, basing his calculations on existing data respecting heights of aerials and distances traversed, discovered

that such intercommunication, if possible, might be accomplished with aerials suspended from masts 3,400 miles high.

That Transatlantic signalling was really Mr. Marconi's objective in the construction of the Poldhu station was a well-kept secret, and, although certain newspapers managed to obtain interviews with the inventor during 1901, no one seemed to have taken seriously any such prospect. A Liverpool newspaper, again very much on the *qui vive*, managed to buttonhole Mr. Marconi in Liverpool one day in November, 1901, and to announce next morning that "Mr. Marconi will be a passenger to-day by the Allan liner *Carthaginian*. . . . He is going out for the purpose of installing a wireless telegraph station on the Newfoundland coast." Then followed some details regarding a chain of stations which Mr. Marconi had in his mind for Newfoundland and the Canadian coast. Needless to state this chain, so far as Mr. Marconi's immediate intentions were concerned, was pure camouflage.

Seventeen Years Ago.

There is no need to detail again the epoch-making events of December 12 and 13, 1901, how the "S" signals sent out from Poldhu between 3 and 6 p.m. Greenwich time were unmistakably heard at St. Johns. The story has been repeated often since that memorable date. Of interest here rather are the impressions which were then created throughout the world. Few were prepared to unreservedly admit the probability of the accomplishment, some were sporting enough to reserve judgment until further details were to hand, and others sought far and wide for "other explanations" of the sounds which Mr. Marconi claimed to have heard. A prominent cable expert frankly unburdened himself of the statement: "In the first place I don't believe it," afterwards suggesting that his scepticism was based on "our own cable tricks." Another "interested," or, shall we say, "disinterested," expert, whilst admitting that signals may have actually been sent across the 1,800 miles of ocean, volunteered the assurance that the "system will never have commercial value."

Sufficient has been here given of the lesser known early history of "wireless" to indicate the weight which was thrown against the new development, until such a time that certain romantic happenings converted the lay public to the opinion that "wireless" was of real importance in many fields of activity. The most unsatisfactory feature of such opposition as prevailed into later years, particularly in the light of present events, is that some of the opponents of radiotelegraphy, when they found the method of direct attack was unsuccessful, did not hesitate to display an interest in rival systems, even to the extent of boosting apparatus "made in Germany."

Had it not been for the dogged persistence of a few who realised the national importance of retaining for Great Britain the prime interest in Mr. Marconi's patents, this country at the outbreak of war might have discovered itself to be absolutely at the mercy of an enemy organisation, dependent possibly on enemy factories for supplies of materials and replacements, and generally, what is known in common parlance as "in the cart."

If, therefore, in the speculations which follow some demand is made upon the imagination and suggestions are made which on the

surface appear fantastic and unpractical, and even inconsistent with present-day scientific knowledge, the history of Marconi's earlier struggles should be kept in mind. At this point, too, would we press home the need at all times for an open mind and a willingness to "test out" the claims brought forward by young experimenters. In the inevitable economic struggle which will follow this war the Anglo-Saxon peoples must not leave anything to chance.

Looking Ahead.

There is certain to be a vast extension of the application of "wireless" to ordinary commercial purposes. Development of the means of communication is essential wherever civilisation and commercial activities hope to make progress. If "wireless" so far has not supplanted the expensive transocean cable, this is no indication that it may not augment the latter over many routes where cables now exist, and prevent the sinking of needless capital in places which, although requiring rapid development, have not yet adequate means of intercourse with the outside world. There are not a few who cling to the belief that cables and "wireless" have distinct fields of utility, but in other quarters young men, whose foresight has earned respect, see the day approaching when, as the cables deteriorate, they will be scrapped in favour of nature's great conductor—the ether. Any further development of the submarine for destructive purposes may also militate against submarine telegraphs and favour the system "sans fils."

Perhaps a sign of the times is provided in the announcement that a French transocean cable company has definitely decided to erect a wireless station for the conduct of uninterrupted communication between France and the United States. Those who are best informed upon recent progress in commercial "wireless" feel certain that this enterprise will be rewarded to a degree far beyond that company's expectations. Germany, which is making no secret of her thankfulness for the wireless service conducted by her high-power station at Nauen, openly expects this station to be her sole direct means of communication with the outer world for some period after the war.

It is stated in well-informed circles that certain cable companies possessing systems extending round the greater part of the globe are now engaged upon experiments for eliminating the relay of messages by intermediate stations. It is not improbable, however, that cable telegraphy, with its start of sixty years over the "stripling" wireless, may be overtaken, if not outpaced, by its youthful rival before the world has seriously settled down again to conditions of peace. During 1917 a wireless operator at Invercargill, New Zealand, found no difficulty in reading messages transmitted from the Eiffel Tower in Paris and Coltano, near the Italian Riviera. The signals from the Eiffel Tower were so strong that they could easily be copied upon a typewriter. We all know that there is a great difference between the technique of receiving messages under laboratory or test-room conditions and the interchange of signals under the exacting commercial demands for speed and accuracy, but the wireless engineer who keeps before him the glorious record of the past twenty years is certain of the future. We venture to state that, if the opportunity is provided for such enterprise, wireless

stations will be erected within the next five or ten years which will be able to communicate direct and under commercial conditions with places as far distant as London and Melbourne. With stations of such power and range suitably placed over the world no ship need ever be out of reach.

The fascinating subject of long-distance wireless telegraphy deserves more space than can be given in the present instance. Whilst the exigencies of warfare have necessitated the suspension of the long-distance commercial services, such as those which were existing between Britain and North America, the United States and Japan, the daily, and one might say almost hourly, issue in this country, under the caption "Admiralty per Wireless Press," of wireless news received instantaneously from (in these days) such telegraphically remote countries as Russia, Rumania, and Turkey, must suggest to many the possibility of further development along the same line. The peace time dissemination by wireless of international information is a matter to which all Governments must give early attention.

We do not refer so much to the radiation of domestic and social news as to the political news of such great importance in the creation of a better understanding between nations. The belief is growing in many quarters that the abolition of secret treaties would largely prevent a repetition of the horrible events which we are at present witnessing. If this be so, then the next most useful factor in this direction would be the general circulation, unabridged, of all political news having international bearing, a procedure which hitherto has not been practised owing to the enormous cost. Even the most powerful news agencies have to limit the amount of their international news to a degree which guarantees them against financial loss, and this means that to a considerable extent the news sent telegraphically from one country to another is inversely proportional in amount and detail to the distance over which it has to travel. Now, with one or more high-powered stations in each land engaged at fixed periods of the day in radiating the most important political news available in the several Government departments, half the world might be reached at the cost of sending a single long-distance cablegram, for it has to be remembered that wireless, unlike cable telegraphy, radiates practically in a circle—unless special arrangements are made to the contrary—and that the same message as might be recorded in America would be simultaneously received in Asia and Africa and all the intervening countries of Europe.

That development upon some such lines is certain is indicated by the fact that the Russian revolutionaries have decided that a chain of wireless stations is necessary for the satisfactory peace development of Russia. Germany, who realised the possibilities of wireless propaganda quite early in the war, may be relied upon to make full use of the etheric medium in times of peace, and it is inconceivable that she should be left unchallenged in advertising herself before the world.

The Wireless Telephone.

But in discussing the wireless distribution of public information we must not overlook the wireless telephone.

Although a state of war has possibly hindered the development of wireless telephony in those countries most intimate with its possi-

bilities, the fact remains that wireless telephony over distances even transocean in extent has already been accomplished. Speech so transmitted very nearly approaches the technical quality of direct conversation. All the vocal inflexions are faithfully reproduced.

There appears to be no serious reason why, before we are many years older, politicians speaking, say, in Parliament, should not be heard simultaneously by wireless in the reporting room of every newspaper office in the United Kingdom. It might be necessary, of course, that each speaker addressed the House from one recognised position, and that around the speaker, as in the case of the existing electrophone, there should be a series of microphones directly connected with a central transmitting station, but our politicians, always alive to the opportunities for publicity, would certainly overlook such technical trifles. Each newspaper office would have its own aerial, receiving gear, and telephones, which would be worn by the reporter detailed to make the notes. The receiving 'phones could be duplicated in order to avoid any break in continuity during the relays.

The field of the wireless telephone, however, is by no means restricted to newspaper work. The same idea might be extended to make possible the correct reproduction in all private residences of Albert Hall or Queen's Hall concerts or the important recitals at the lesser rendezvous of the musical world. That these suggestions are no mere flights of imagination is revealed in the fact that on one occasion at least within the last twelve months a dance was held in the United States to the strains of music transmitted by wireless from an orchestra several miles away

Audible Advertisements.

Such departures would expose us, of course, to all sorts of logical but unwelcome developments. There would be no technical difficulty in the way of an enterprising advertisement agency arranging for the interval in the musical programme to be filled with audible advertisements, pathetic or forcible appeals—in appropriate tones—on behalf of somebody's soap or tomato ketchup. Even to-day the departments of food economy and War Savings might provide periodic stentorian exhortations by wirelessly operated megaphones established at the traffic centres. The experiment would have the advantage of protection by the Defence of the Realm Act.

'Twixt Earth and Heaven.

The present war has demonstrated very clearly the certainty of still further extraordinary advances in mechanical flight. Military requirements have sufficiently revealed the possibility of constructing aeroplanes capable of carrying considerable loads over very long distances. In the intensive commercial life which will be thrust upon us to make good the ravages of the present conflict there will certainly arise a need for such speedy long-distance transit as the aeroplane alone can afford. There are many persons, theatrical managers, for instance, to whom a non-stop Transatlantic flight, costly though it might be, would be a profitable adventure even from the point of view of the value of time saved. One of the essentials for long-distance aerial traffic will be a complete wireless system enabling the aeroplane

to keep in touch with mundane affairs throughout the journey, and to signal in turn to stations below as the journey progresses. We can imagine the value of wireless to an aeroplane setting out, say, from London to Vladivostock, which, on approaching the Urals, learns of a violent storm travelling westwards from Siberia. How useful, too, would wireless be if that same machine, crossing the inhospitable wastes of Siberia, and compelled to land at some out of the way spot, could give to the nearest land station an indication of its predicament.

Such a wireless equipment operated in conjunction with a systematic arrangement of stations on *terra firma* would enable the pilot to maintain his course even above a sea of low-lying clouds. Aerial navigation under such conditions would be relatively independent of the weather.

By the same system of relays there should be no great difficulty in the way of a commercial magnate, riding at two or three hundred miles per hour above the Pyramids of Egypt or the hilltop monasteries of Thibet, receiving the latest Stock Exchange news and giving thereon his directions to his brokers. In those days, not so very far distant, we shall have something approaching hustled history.

Even treating aviation as a sport, and the military requirements of the future will demand for it even wider recognition and support than has been given in the past to fox-hunting and steeplechasing, there will be an imperative need for some system of wireless warnings if the fickle atmospheric conditions of this country are not to claim an undue number of lives. It should not be at all difficult to standardise means for conveying such information to cross-country fliers. Each aerodrome—and there will be hundreds constructed throughout the kingdom—must have its wireless signal station operating in conjunction with a local weather bureau.

This same forced growth of aerial activity will undoubtedly stimulate research into weather conditions. For several years wireless has played a useful part in the quest for meteorological information, much of the most valuable data on the charts issued by the meteorological offices of the several Governments having been received from ships at sea. Some day, when the organisation is sufficiently well advanced, we shall have all big farmers placing themselves in wireless touch with the meteorological office by installing a special receiving apparatus. Much valuable time would be saved even to-day by a wider and simultaneous dissemination of weather warnings. This, of course, especially applies to farming in the colonies and to planting in semi-tropical climates.

Already there are in existence marine " danger signals " operated under wireless control. As far as we can see there is certainly no reason why many lighthouses, which are little more than prisons for the devoted watchers, should not be controlled from the shore by impulses radiated at sundown and sunrise and at such times as storms break over the neighbourhood. Instead of many groups of watchers there would then be need only for an inspecting staff which would pay periodic visits to refill the gas containers and make any necessary adjustments. When more is known about the utilisation of wave and tidal power, the need for constant attention to the source of light will also disappear.

In any case, should it be deemed advisable to maintain lighthouse crews at many of the most exposed positions, there is very good reason for establishing wireless intercommunication with the nearest coast station. Not only would life be made more tolerable to the men on the rocks but warnings might be exchanged of considerable value to navigators.

In the Backwoods.

Whilst it is already obvious that great expanses of territory, like the continents of Africa, Asia, and South America, provide almost unlimited scope for wireless intercommunication, it is probably not so well known that the actual surveying of those countries can be undertaken to a wonderful degree of accuracy by "wireless" means. By a very simple application of the wireless direction-finder it is possible to triangulate vast areas of territory at a speed quite impossible by any other present method.

One of the great factors which will materially assist to popularise wireless for pioneering, prospecting, or even Polar exploration is the wonderful degree of portability now reached by the employment of more sensitive receiving gear. Apparatus capable of reliably transmitting from 50 to 75 miles has been constructed with a total weight of not more than 10 lbs., whilst practical sets suitable for transmitting messages from 10 to 20 miles have been produced, having a total weight of 5 lbs. Pocket wireless only exists so far in the minds of the writers of thrilling spy stories, but the day is very near at hand when light portable sets might be introduced for a variety of useful purposes. Two special applications from that progressive country, the United States of America, may particularly appeal to British authorities.

During the rainy season in Southern California great havoc is often wrought in the matter of a few hours by streams washing away bridges and flooding roads, and thereby interrupting vital communications. In order to ascertain the conditions of the highway and secure their immediate repair, the responsible authority have mounted a portable wireless outfit of considerable range on a motor lorry, capable of carrying the apparatus and fifteen men at a speed of 30 miles per hour. Immediately a serious "fault" in the highway is discovered light aerials are run up and the fact notified to headquarters. On advice from headquarters that the situation is appreciated, and preparations have been made for a breakdown gang, the "Trouble Hunters" pack up their wireless and continue their tour.

The New York police possess motor vans equipped with wireless which enable them to keep in touch with headquarters when engaged upon any task requiring constant intercommunication. The New York river police also have wireless installations on their patrol boats, and this, we are informed, has wonderfully facilitated the work of defeating the designs of enemy agents in that vast network of waterways known as New York harbour. We are surprised that greater use has not been made of wireless for police and fire service on the Thames and at other ports in the United Kingdom.

A few years ago a romantic touch was given to a successful piece of criminal investigation by the use of wireless for the tracking down of the murderer Crippen. The conditions were such, however, that the criminal's identity was practically established on the descriptions

wirelessed to the liner by the Scotland Yard officials. The wireless transmission of photographs is by no means outside the realm of possibility, and some day, not very far distant, it may be possible to provide not merely wirelessly operated tape-machines in mid-Atlantic but pictures illustrative of the days' events. The nightmare of wireless television is unlikely to become a reality for some time. Mechanical and electrical difficulties exist which require for their solution a much more complete knowledge of the nature of light, electricity, and ether. Some day the solution may be forthcoming, but, as such an invention would be of questionable popularity and its commercial application limited, the inventive faculties in most countries are likely for the present to be turned in other directions.

Late in the autumn the lay world was surprised by an Admiralty announcement of an attack upon British ships by an electrically controlled boat. The device, it subsequently appeared, was an elaboration of one brought to the notice of the British Admiralty many years ago, the only new feature being that the control of the craft was directed in the first instance by wireless from a naval aeroplane. The Press undoubtedly were on the safe side in regarding the idea as somewhat clumsy in conception and doomed to failure, particularly as we sank the newcomer and the newcomer did not sink our ships. The wireless control of torpedoes and similar devices is a fascinating problem which has received the attention of quite a number of imaginative persons. The contributions made by Englishmen, however, for some inexplicable reason have always been given less publicity here than the experiments of foreigners. Wireless control of this character has been demonstrated in the case of models, or over limited distances, for some years past, but any serious development beyond the experimental stage has always been hampered by the difficulty that it is obviously impossible to control to any effect an object outside the range of vision. The rapid progress of aviation and the equipment of aeroplanes with radio apparatus introduce quite a new factor into distant control and suggest a wide field for wireless in the warfare of the future. One can foreese new horrors, such as the ignition by wireless from aeroplanes of land mines buried prior to an evacuation or a retreat and the wireless release of poison gas from buried containers.

When nature's wide use of "wireless" is reflected upon, one is tempted to wonder whether as our knowledge of the ether progresses some means may not be discovered of transmitting "power" without the use of metallic conductors. At present, of course, only an infinitesimal portion of the power utilised in sending wireless signals is intercepted at distant receiving stations, and with our existing data it does not appear likely that the actual transference of energy without hopelessly high losses on the way is at all possible—but——; what did our greatest physicists think of the prospects of wireless telegraphy less than a quarter of a century ago?

A Wide Field for Young Anglo-Saxons.

If we have exposed ourselves to the charge of tedium in this review of "possibilities," the risk has been taken in order to indicate not only the wonderful scope for wireless research but something of the field opened to wireless engineering. Until now the man in the

street has been so entertained by the romantic results attained by wireless at sea that we suspect he has given but little thought to the activities behind the scenes in physical laboratories, drawing offices and workshops which have made possible such gratifying successes.

Behind the many thousands of Marconi operators who bravely face grave risks in the privileged task of protecting human life are large groups of men working silently, but none the less enthusiastically, on the solution of etheric problems and the construction of wireless apparatus. It is of direct interest to the English-speaking peoples, with their gigantic naval and mercantile fleets and world-wide territory, and also to the progress of civilisation, that this ever-growing army of wireless workers should draw to its ranks from amongst these peoples ever-increasing numbers of young men of ability and genius, men with open minds and the most liberal education the respective countries can bestow. It is to be hoped that the great technical institutes and the public schools which display a pride in their modern side will appreciate at once the prospects of wireless engineering as a career, and bring to the notice of those best in a position to judge such students as display talents likely to assist in extending the field of radio control.

WIRELESS TELEPHONY ON AEROPLANES

C. E. Prince

WIRELESS TELEPHONY ON AEROPLANES.

By Major C. E. PRINCE, O.B.E.

(*Paper received* 17 *January, and read at a* WIRELESS SECTIONAL MEETING OF THE INSTITUTION, 18 *February*, 1920.)

Wireless telephony in aeroplanes having been born in the Great War, and having been developed under that terrific stimulus, it is hard to approach the subject except from this standpoint, or to avoid the historical method of treating it. It is impossible in this paper to make more than a very brief survey of a large subject, but the author trusts that it may be of interest to give some account of its genesis, and of how the technical difficulties were met and conquered.

The subject of wireless telephony is in itself a combination of two others, namely, telephony as understood in ordinary line working, and wireless telegraphy with its group of associated problems. The present paper will treat both of these as well understood, and will be confined mainly to the special application of wireless telephony to aircraft, with which the author was so closely associated.

After the outbreak of war, while carrying on experiments at Brooklands, mainly with a view to producing a continuous-wave valve transmitter sufficiently simple and practical to be used in the air by unskilled personnel, the author was struck by the great advantage which would be gained by the use of articulate speech instead of Morse, if it were possible, for artillery observation and reconnaissance. It was obvious that a fleeting target would be more quickly indicated, or a location described by word of mouth, than by a system of slow and laborious telegraphy and map references.

A skeleton set was made up and tried in the air, and at the first attempt some approximation to intelligible speech was received.

This was in the summer of 1915, and it is believed to be the very first occasion in the world when wireless speech was received from an aeroplane.

In spite of this initial success, the difficulties in the way of producing good articulation, and a light and practical set, appeared to be almost insuperable; but they were gradually surmounted, and to-day good telephony is possible not only from air to ground, but from ground to air, and—most difficult problem of all—from machine to machine.

At that period the soft valve was in use, with a lime-coated platinum filament, and the handling of this by unskilled persons was one of the greatest difficulties. Except for this the purely electrical difficulties have throughout been far less serious than the telephonic, practical, and mechanical ones.

In the first place the transmitter must work in a region of intense noise, vibration, and often violent air disturbances, in which even the real human voice is unable to speak to the human ear over a greater distance than a very few inches; in which the velocities of the air currents are alone enough to cause distortion, and the very muscles of the face can hardly retain their true shape under the varying wind pressures.

When it is remembered that under these extreme conditions speech has to be converted into current modulations, these modulations radiated, received, rectified, magnified, reconverted into sound, and again heard by a human ear set amid a similar uproar, the final achievement of inter-machine telephony will be appreciated.

In the early stages the difficulties of reception of speech in the air were so great that only transmission from air to ground was attempted, and the first practical set evolved was a transmitter, capable of employing either speech, continuous wave, or interrupted continuous wave (subsequently called "tonic train").

The circuits employed are shown in Fig. 1.

It will be seen that it was essentially a self-contained oscillating system, to which the aerial was loosely coupled. The microphone was inserted in the earth-lead, and modulated the radiation by varying the resistance of the aerial. The valve was not in view, but the set was provided with three meters, A showing the aerial, *a* the filament, and M A the high-tension feed currents; the readings of which gave all the information necessary to make the adjustments. The plug (P) served to bring into action either the microphone (M), buzzer (B), or to complete the circuit of the artificial aerial (A A). If not plugged in, the set worked as a plain, continuous wave-transmitter. The key was mounted on the top of the set, which was suspended by a three-point rubber suspension. High-tension current was supplied at 600 volts from a dry battery of small cells, weighing about 36 lb., made up in a flat form and usually carried under the footboards.

The microphone used was selected from a variety of ground types and, originally, was suspended on rubber in a frame held in the hand.

Some of the best ground microphones proved useless in the air, and the choice finally rested on an old-type Hunnings Cone. It is interesting to note that it is almost impossible to predict from its behaviour on the ground whether any particular microphone or type of microphone will work satisfactorily in an aeroplane; and in the Royal Air Force every individual instrument was tested actually in the air.

The set above described weighed, without batteries, 10 lb. It was used on a trailing aerial 250 feet long and employed a wave-length of approximately 300 metres, not very far removed from the natural wave-length of the aerial. In consequence, the radiation was very good. On one occasion when the author was giving a demonstration before the late Lord Kitchener at St. Omer in February 1916, the spoken messages were

picked up and recorded by the Lowestoft interception station at a distance of over 100 miles, although the aerial current in the transmitting aerial was less than 0·25 ampere.

The author was admirably assisted in the production of this set by Lieutenant (now Captain) McDougald, R.A.F.; and, remembering that it was the first practical aeroplane telephone ever produced, and in the alternative use of various types of transmission it anticipated the latest international regulations, he cannot dissemble a feeling of satisfaction that the British Royal Flying Corps was the pioneer in a subject which has subsequently become of international importance.

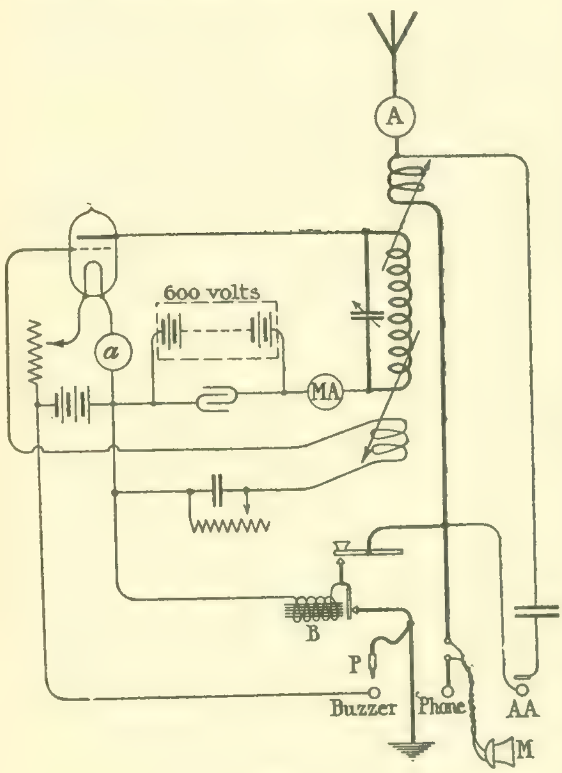


Fig. 1.

This transmission was at first received on the ground on a Marconi double magnification-circuit in which a single soft valve was employed for both high-frequency and low-frequency magnification, a carborundum crystal being used for rectification. Reaction was used to the utmost, and great sensitiveness was obtained. The ordinary working limit of range from air to ground was about 20 miles for telephony, 30 to 35 for tonic train, and about double this distance for pure continuous-wave.

At this time, although experiments in telephony were continually proceeding, it was thought that, in view of the difficulty of receiving speech in the air, it would prove most practical for immediate requirements to transmit to the air by Morse only, and, to this end, the author made up a valve receiver with one soft valve, with practically similar circuits to the ground set. This was tested in the autumn of 1916, and ranges of from 30 to 50 miles were obtained from a ½ kw. spark set It was, as a matter of fact, on this receiver that intelligible speech was first heard in the air and the idea of "remote control" originated. Its adjustments proved, however, rather difficult for unskilled personnel.

The overseas Forces, nevertheless, did not for a long time make any use of air-to-ground telephony, although just before the Armistice a meeting of the Higher Commands recommended its introduction for reconnaissance and similar work, as originally suggested in 1915.

An urgent demand arose, however, for telephonic communications between machines in the air, and all energies were devoted to solving this far more difficult problem.

In considering the application of wireless to aircraft it is important to remember that, besides working under difficult conditions, it was necessarily operated either by quite unskilled personnel, or by those who could only receive a very slight training. It was this, also, that favoured—nay even made essential—telephony as against telegraphy. The average pilot or observer could not have sufficient acquaintance with Morse to read it subconsciously, nor had he the time or inclination for it amid the multifarious calls on his attention while flying. Thus, although it would have been far easier to equip him with Morse communication, it was practically useless. For various reasons, also, there was for a long time no demand for both-way working, and a machine was equipped either for transmission (for the leader to give orders), or reception (for his formation to receive them).

For similar reasons it was necessary to eliminate all possible adjustments; and to show to what extent this was successfully achieved, it may be briefly stated that the transmitting apparatus had none, and the receiving apparatus only two, one of which was seldom touched.

As always, easy working implied difficult designing, and it may be interesting to trace a few of the steps that led up to the chosen methods.

The problem was rendered easier, because by this time the general advance had provided us with a reliable, small, hard transmitting valve of French type, capable of handling about 20 watts, and similar valves with slightly more open grid for use in reception.

Dealing first with the transmitting apparatus, an ordinary reaction or regenerative circuit provided the radio power; and the only electrical difficulty was the choice of the best method out of the many alternatives of applying the voice modulations.

The coupled-circuit system already described, although giving very perfect results for small power, was ruled out on account of the coupling and tuning adjustments and its output limitations.

The following simpler circuit, devised by the author, was also abandoned, but as it is not uninteresting it may be worth describing.

In this, a condenser of about 0·05 mfd. capacity was placed in the earth lead of a simple oscillator. Its insertion or short-circuiting produced little difference in the aerial current; but if a microphone was connected

across it, the loss of energy in this was equivalent to an alteration in the total resistance of the aerial, and by choosing suitable constants and adjustments good variation could be obtained and "breaking" avoided. It has a critical reaction adjustment, and also tends rather seriously to change the wave-length as well as the intensity of the radiation; so that it can give good or bad speech according to the adjustment of the receiver, for reasons about to be described.

In comparing different means of modulation, in every known method (as far as the author is aware) variations of intensity or output are always accompanied by some change of wave-length, and the receiver can be adapted to take advantage of one or the other factor, so that, strictly speaking, any type of transmission should be considered in relation to its reception. Thus, for instance, a receiver in which reaction is relied on, with a very steep and peaky resonance curve, is peculiarly sensitive to wave-length changes; whereas the modern type of flatly tuned high-frequency amplification receiver, *ipso facto*, takes no account of this, but responds alone to changes of amplitude or intensity.

In practice both factors can be laid under contribution at the receiving end, though probably the ideal method of modulation would change intensity only.

In any system in which the change of wave-length preponderates, good or bad articulation can actually be produced on a reaction receiver according to the slope of the resonance curve on which the adjustment is made.

When, in any receiver, reaction is pushed to the utmost short of oscillation, the resonance curve becomes amazingly steep and the sensitiveness very great, and most remarkable effects can be obtained if the tuning be then adjusted very finely. It is unnecessary, as in self-heterodyne, to detune; and so full advantage can be taken, by this critical condition, of any change of wave-length, which probably accounts for many of the freak ranges accomplished by this type of apparatus. It is easily seen that a very slight change of wave-length will produce enormous variations of intensity in the receiver, but it is equally obvious that there must be considerable distortion of speech quality, since the true proportionality is lost.

To return, after this digression, to our point of departure, no method of controlling the radiation directly by the microphone proved free from grave disadvantages, and the choice therefore fell on some form of indirect control, of which the most obvious was the placing of a microphone transformer in the grid of the oscillating valve. This, though giving very good results, was abandoned in favour of the final arrangement about to be described and now generally known as "choke control," in which the modulation is applied to the anode circuit of the control valve.

The principle of this system may be made most clear by approaching it step by step.

Let us suppose that in the anode feed circuit of a simple valve oscillator is placed the secondary winding of an ordinary step-up transformer, the primary of which is a microphone and battery circuit (Fig. 2). The variations produced by the voice will give rise to changes of potential in the anode feed circuit, which will be equivalent to supplying the oscillating valve with more or less high tension, and will alter the radiation in a sympathetic manner. Since, however, the energy dealt with will be weak compared with the main supply, success will be only partial. For magnifying this effect let us now introduce another or "control" valve whose grid is acted on by the original microphone transformer, and whose anode is in series with a one-to-one transformer in place of the original one. If the two valves are comparable and supplied with similar high tension, we are now able to apply a modulation or variation of the same order as the energy dealt with by the first or "power" valve.

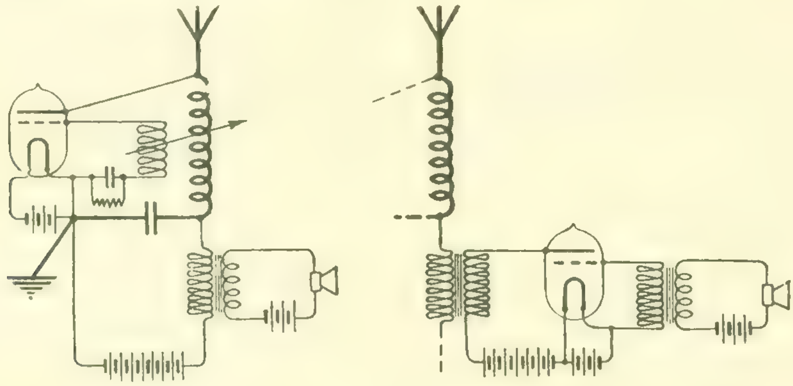


FIG. 2.

From this point some easy steps will take us to the actual circuit employed. The control valve can be supplied from the same source of high tension as the power valve; the transformer can become a choke coil (which is, in effect, a one-to-one transformer), and it is an obvious arrangement to work the filaments and the microphone primary circuit off the same low-tension battery.

The circuit now becomes as shown in Fig. 3, in which P is the power and C the control valve, L is the choke coil, and T the microphone transformer. H T is the source of high-tension supply, and F is the filament battery.

It will be seen that the anodes of both valves draw their high-tension d.c. supply through the choke winding, and as long as the microphone is quiescent, the output and general behaviour do not differ from that of the power circuit considered as a plain one-valve oscillator. When, however, variations take place in the control-valve anode circuit at speech frequency, very large surges are set up in that of the power valve, which may approximate to the original high-tension d.c. potential and so sweep the output from nearly double its steady value to almost zero. To give some quantitative idea of the forces involved, the following data, taken from

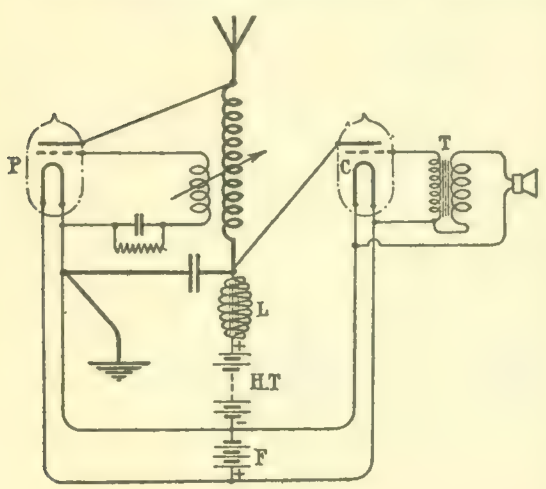


Fig. 3.

the small 20-watt R.A.F. set working on 600 volts high-tension d.c. supply, may be interesting.

> Swing of grid potential on control valve, i.e. potential change on secondary of transformer with a loud vowel: 90 volts each side of zero, or 180 volts total.
>
> Surge voltages across choke coil measured on electrostatic voltmeter on no load: (about) 700 volts; on load, that is with power valve in operation, 300 to 400 volts.

It is important to notice that although the control valve does not appear at first sight to contribute to the output, it actually does so; for the changes induced by it do actually swing equally above and below the line of normal output, that is, of the "carrier wave," albeit they are too rapid to produce any effect on the slowly acting aerial ammeter; and thus the choke control is of approximately double the effectiveness of one valve with grid control, whose variations can only be between normal and zero output. It is not ordinarily possible with two similar valves to produce changes quite equal to the output acted on, which is in many ways an advantage, as it makes for stability; and under certain circumstances it may be an improvement to add a third or magnifying valve in the control system.

Choke control proved pre-eminently suitable for air working, and no other method of modulation survived in competition with it. There are absolutely no critical adjustments anywhere. Almost every constant can be changed within quite wide limits, and though it may thus be caused to work more or less efficiently, it never reaches a point of complete failure. Moreover, where the set is subject to considerable increases of anode potential, grid control, which is a constant depending on the microphone system, becomes less in proportion to the output; whereas in choke control, since the modulating valve is fed from the same high tension, the "degree of control" is subject to this diminution.

The action of the choke was subsequently investigated with more accuracy than was possible in the hurry of war design, and some interesting results were obtained. For a sound frequency of 750 per second an inductance of not less than 5 henries is required; after that, the curve flattens out, and almost any higher value is immaterial. Resistance, as such, however, is always detrimental. The author has suggested, but never tried, the deliberate filtering out of the lower speech frequencies by too small a choke coil, in order to favour the higher harmonics.

In practice these are so important that the action of the iron core, while by no means negligible, is not preponderant; and, in fact, the best results often seem to be given by a choke coil in which the core is already saturated by the permanent feed current.

The little 20-watt choke control set, designed by the author on the principles outlined above, was very successful and became the standard R.A.F. set with which all the air transmission has, up to the present, been done.

Turning now to what may be called the accessories and general lay-out of the set (Fig. 4), one of its features, which was largely responsible for its success, was the use of "remote control" (which will be treated of at greater length in speaking of the receiver).

Things were so arranged that the set proper could be mounted at a distance in any convenient position, and only a very small control unit for operating it was brought within reach of the user's hand. In the case of the transmitter no adjustments were necessary, as a fixed wave-length, a definite aerial, and fixed reaction were used, so that the control unit carried only a switch, an aerial ammeter, and plugs for microphone and telephone receiver. The aerial ammeter was for the user's purpose merely an indicator that all was well, and he needed to pay no attention to its exact reading.

The switch fulfilled rather a complex function, as it made or broke the dynamo field, filament and microphone circuits, so that when it was off every circuit was dead. Remote control not only was useful in machines where space was strictly limited, but tended to mental directness—a very important point in war instruments—by removing from the user's contemplation all technical complexities.

From his point of view, then, it was necessary merely to

switch on and talk. Simplification could go no further; but how necessary this was, can only be appreciated, perhaps, by those familiar with air work. It is probable that much of the British lead was due to consistently designing to fulfil at all costs the needs of actual service conditions, rather than to a laboratory standard.

Although the first telephone had been supplied with high-tension current from dry cells, these had been completely superseded by small air-driven generators,

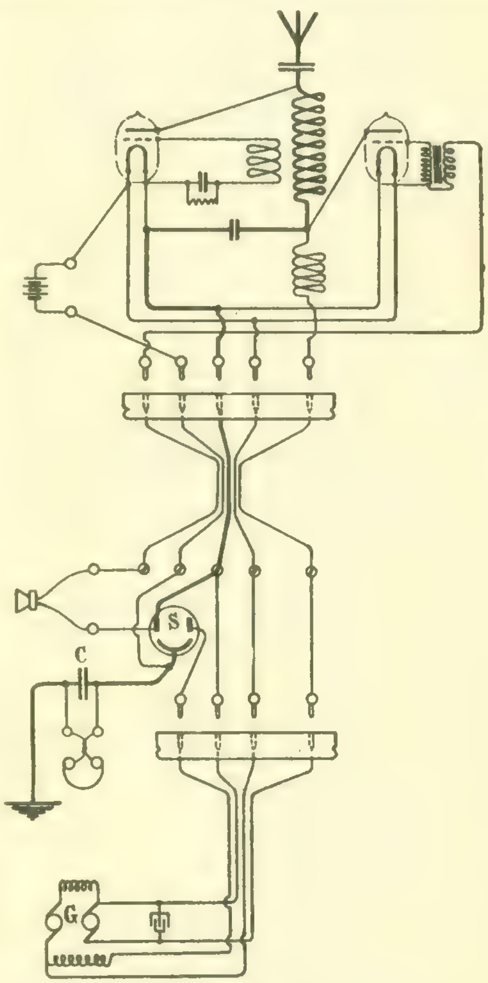


FIG. 4.

the improved descendants of one made for the author by Mr. Mackie early in 1916. Briefly, the standard generator (G) adopted gave about 600 volts from one commutator at its normal speed of 4,000 r.p.m., while the 6-volt filament accumulators were floating across the low-tension side. Moderately good electrical regulation was provided by a demagnetizing field-winding system, and in this way the size of the accumulator had not to be very great.

A small but interesting point about the set was the provision of "side-tone." It was found to be highly important that the speaker should be able to hear the effect of his own voice, and to do this in the simplest possible way a condenser (C) of about 5 jars' capacity was placed in the earth lead, and across it a pair of head receivers was connected, which were thus enabled to pick up the low-frequency effect. By connecting another pair in parallel, the other occupant of the aeroplane could also hear what orders were given.

Such then, very briefly, was the complete set as originally used in two-seater machines, for transmitting only, except that we have not yet treated of the microphone proper.

The importance of this is obvious, and only the barest outline can be given of what is a complete subject in itself; one in which opinion constantly sways from side to side, and which is at once difficult and easy. Opinion is no loose word; for in telephonic work under air conditions it is almost hopeless to expect exact or definite results from one experiment, and the only real guide is the mental summary of prolonged experience.

The disturbing elements may be set down as: (1) mechanical, and (2) acoustical. In the former the principal are the shaking up of the carbon granules by movements of their container, and the slow distortions of the diaphragm under varying air-pressures. Neither of these difficulties is very serious, and the first-named is almost completely eliminated by holding the microphone in the hand—the finest possible shock absorber.

The acoustical difficulties are far worse, and principally lie in this: that the noises which it is desirable to reject are of the same order as the sounds that are to be accepted.

After much experiment the Gordian knot was cut thus: by devising a microphone almost insensitive to sounds of the noise intensity, but responsive to the powerful concentrated sound waves of a voice impinging upon it from a very short distance. In other words, the voice was raised to a higher power, as it were, by speaking very loudly, and thus two distinct orders of intensity were produced, which could be separated. By choosing a suitable thickness of diaphragm, size of granule, tightness of packing, etc., combined with heavy damping, a satisfactory microphone was arrived at. It appeared curiously dead and ineffective on the ground, but seemed to take on a new sprightliness in the air. Of course in the quieter types of machines a more sensitive and more normal microphone was not only possible, but better; but nothing else was able to work so effectively in, say, a noisy Bristol fighter. A microphone has recently been patented with adjustable damping,* which ought to prove very useful.

We now turn from transmitting to its complement, receiving in the air. When the general uproar is remembered, the difficulties need no emphasis. The problem here was to combine considerable sensitiveness, loud signals free from distortion, and the minimum of adjustment.

It was only comparatively lately that high-frequency magnification became sufficiently manageable for introduction into aircraft, and low frequency could not be

* By Captain J. M. Furnival: Patent No. 16712/1919.

pushed very far without making a set far too sensitive to mechanical shocks. The arrangement which, as the fittest, survived, consisted essentially of a detector valve with reaction, and two note magnifications. The detector valve was not energized direct from the aerial, but through a so-called "aperiodic" circuit, which was really a circuit approximately syntonized by its self-capacity This has always been found to reduce magneto noise considerably.

The application of remote control to the receiver really antedates its adoption on the transmitter, and is not, as with the latter, a mere matter of mechanical lay-out, but involves a technical point of some interest. In some air-trials with the early 1916 soft-valve receiver, it was noticed that to alter the filament brightness made a very convenient way of finally controlling the reaction, after the circuit had been set near the critical point; and at Captain Furnival's suggestion a "banjo wire" resistance was made up and mounted on the joy-stick, so that the pilot could make the last fine adjustment himself. Subsequently, during the continuance of the general efforts to produce a really satisfactory aircraft receiver, when many a promising design wilted in the fiery trial of actual air work, the author persevered with the principle and had the satisfaction of seeing the "remote control" prove its usefulness.

The principle involved is, that the increase in emission caused by brightening the filament of the detector valve, whose anode current is concerned in the reaction, steepens the characteristic curve and so determines the oscillatory condition, when the circuits have been adjusted near the critical point; a condition which can easily be provided for in the design. The adoption of this principle had a large share in the success of the aircraft telephone, partly for the mechanical reason of having only a small control unit near the user, and also because to alter the reaction electrically in this way makes but an infinitesimal change in wave-length; whereas in mechanical methods small changes of capacity are inevitable with every adjustment, and necessitate a slight retuning, so that it needs some skill and finesse to get the best results. With this remote control, however, the user could get the tuning once for all, and adjust the reaction freely for the best effect by a safe and easy change in a low-frequency non-oscillatory circuit.

The remainder of the receiving circuits calls for little comment in a brief survey such as this, as they will be clearly understood from Fig. 5, and attention should now be given to the next step in advance.

Although prior to the War high-frequency magnification by resonance methods had been in use, there was a general recrudescence of attempts to effect it by simple means, aperiodically if possible, in which the French experts had taken a leading part. This resulted in such methods as the well-known condenser-resistance circuit, and one in which transformers with an iron core, highly laminated, were employed to deal with radio frequencies, and worked efficiently over large ranges of wave-lengths. The whole subject at this stage was somewhat nebulous until Captain Round, in a few weeks' admirable investigation, unified and correlated the various circuits, showing how all such transformers could be considered to be essentially resonance transformers, differing only in damping; so that it lay with the designer to choose small damping, large magnification per valve, a limited number of valves, small range of wave-length and a rather tricky circuit, or the reverse of all these, resulting in a stable flatly-tuned arrangement—or any intermediate conditions. Special low-capacity valves were introduced, so that the damping produced by them could be made a maximum, and high-frequency magnification was tamed and harnessed. A cascade series of such valves could be set up, working with fairly constant efficiency over a large range of wave-length, so that no tuning (within these limits) was needful except that of the circuit applied to them.

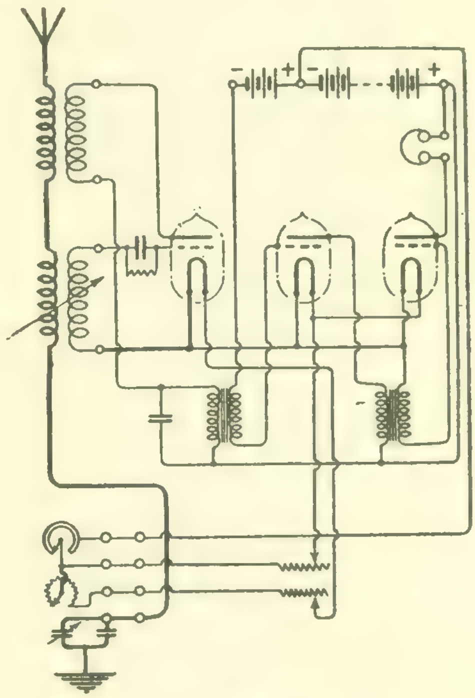


FIG. 5.

The first fruit of this advance, as far as aircraft sets were concerned, was a five-valve receiver, designed by Major Whiddington, in which a choice was made of two high-frequency magnifications and two low, with a detector valve.

This set, which unfortunately could not be manufactured in quantities in time to play much part in the War, was, as compared with the former three-valve receiver, about 10 times as sensitive for strong signals, and 30 times for weak ones.

It was intended for use with fixed aerials rigidly connected to the wings and fuselage of the aeroplane—as opposed to the trailing aerial, which was a great embarrassment in fighting. In spite of the diminished radiation of such an aerial, the increased sensibility of

this receiver approximately restored the usual range. Fig. 6 represents a typical circuit of this kind and shows one high and one low-frequency magnification, with a fine-grid rectifying valve between. Increased sensitivity as well as the nearer average approach of the aerial system to the source of disturbance, made more apparent, however, one of the great bugbears of air work where great sensitiveness is necessary—magneto noise.

This, again, is a subject in itself, on which a vast amount of work has been done; and as it applies equally to all aircraft wireless, no attempt will be made to treat of it in the present paper.

Since the new type of receiver had not come into general use up to the time of the Armistice, all the actual work was done with the three-valve receiver and transmitter already described. Trailing aerial wires of 120 ft. length were used in the transmitting machines, with an aerial current of the order of 0·4 ampere, while the receiving machines had aerials of from 80 to 100 feet in length. The normal safe working range from machine to machine was about 4 miles (though this was often very much exceeded), while the range to a ground station was from 20 to 50 miles or more.

A flight or squadron of machines equipped with this apparatus could set out and fight or manœuvre in formation under the orders of their commander, whose machine only was fitted for transmission. So great was the importance of telephony considered to be, that a special school of wireless telephony was instituted under Captain Furnival, who had been one of the author's earliest assistants, and through this school passed every week about 36 fighting pilots for a course of instruction in using the apparatus and in the important art of proper articulation in the air. Special wireless officers also were trained at this school for the task of equipment and maintenance, and thus a whole organization grew up, as wireless telephony threatened to supersede all other means of communication for aircraft.

It took on great importance, too, for home defence against air raids; and a chain of ground stations of considerable power was put up (technically exactly similar to the aircraft transmitter on a larger scale) which were capable of transmitting up to about 100 miles to a machine in the air, in order to warn the patrols of the approach of an enemy. Telephony from the first of these stations was loud enough to interfere with work overseas in the neighbourhood of Arras. This work involved the fitting of receiving as well as transmitting gear in the leader's machine, and from this and other causes arose a demand for both-way working, which was easily satisfied by fitting both the standard sets in all necessary machines and arranging some form of switch-over.

In consequence of the greater ease of reception at a quiet ground station, and its superior transmitting power, the to-and-fro ranges became approximately equalized, in spite of the disparity of output, and a machine could speak or be spoken to at distances of the order of 70 to 100 miles.

After the signing of the Armistice the Cologne postal service was equipped, both ground and air, entirely with the little aircraft sets and some remarkable results were obtained. The ground stations, which had 70 ft. masts, were set at 50 miles apart, and could transmit 30 miles to a machine, or receive from a machine at a distance of about 50 miles. These are conservative figures, and frequently an intermediate station could be omitted and a machine could be in communication with three of the stations on the route. This was installed and equipped by a wireless telephone section organized for the purpose at Marquise. The central station on this route handled 5,000 messages during the 5 months it was in operation.

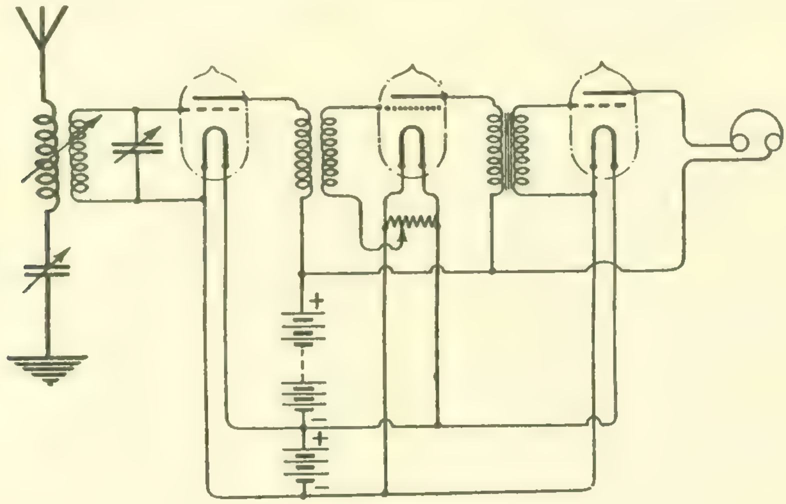


Fig. 6.

It only remains to indicate the lines on which the most recent apparatus with which the author is concerned is developing.

The International Convention having laid this down as the maximum allowable, the transmitter will deal with an input of 100 watts, and choke control will be retained. All types of transmission will be provided for. The receiver will have three high-frequency magnifications and one low, making with the detector five valves, and the combined transmitter and receiver will be worked from one remote control. Batteries will have to be retained at present for filament lighting, but they can be small ones floating across the generator; and there seems good reason to hope that in the near future a perfectly silenced and regulated generator will permit of the abolition of the battery, all current, even for the receiver, being supplied direct from the dynamo.

Ground stations will be equipped for direction-finding with a transmitting mast one or two hundred yards away controlled from the receiving building, and matters will probably be so arranged that the ordinary P.O. land lines can be plugged direct on to the wireless, so that a man may talk direct from his office to a machine in the air.

Unfortunately, switching-over will still be necessary until such time as the ideas which will shortly be set forth in a paper by Captain Eckersley come to fruition.

In conclusion the author wishes to express his thanks to the Air Ministry for permission to use the information given in this paper, and he would like to pay tribute to the memory of the late Captain Cecil Marks, to whose enthusiasm and encouragement was due almost the very birth of aircraft telephony, and whose death in action was a real loss. Moreover, no paper on this subject would be complete without mentioning the names of Captain McDougald and Captain Furnival, the author's earliest assistants and co-workers, or that of Major Robert Orme, who was for so long the loved and able Commanding Officer of the R.F.C. experimental wireless.

Discussion.

Captain J. M. Furnival: An interesting point in connection with the development of the pilot-operated set is that of the substitution of high-frequency magnification for the reaction and low-frequency circuit employed in the Mark III tuner. This is surely a big step in advance not merely from the point of view of a gain in sensitiveness, but rather of increase in reliability. To depend on reaction for ranges, the greatest care and experience is necessary, especially where test flights are few and far between. It is rather a problem to arrange an efficient ground test which will indicate truly that the set will come up to oscillation point in the way it should in the air. I think this was one of the main troubles of the maintenance officers, and one which will quite disappear with the introduction of high-frequency magnification. Under the subject of speech control, the author mentions that in certain conditions it is an advantage to employ an additional control valve on wireless-telephone transmitting sets. Such a system was successfully applied, I think, by Captain Murphy to an R.A.F. 11 transmitter at Marquise. In this case a small 20-watt service valve was successfully employed, thereby considerably increasing the efficiency of the station. There is a point in connection with the design of the air microphone which is perhaps worth mentioning. Not only is it necessary to choose a diaphragm of suitable thickness, but the actual material of which it is made is important. Various substances were tried, namely, carbon, steel, ebonite, celluloid, aluminium, and mica. Mica is the best, probably being a substance the natural period of which is least affected by engine noise. Aluminium also gives good results. It is interesting to note that the diaphragm of a gramophone is made of mica, and in this case also there is a certain amount of extraneous noise, due to the needle rubbing over the record, which it is necessary to suppress as far as possible. I should also like to mention the work of the wireless telephone officers, both wireless and flying, of the Royal Air Force who by their enthusiasm and combined efforts broke down the barriers of natural prejudice and laid the foundation of an organized wireless telephone service, which it is obvious will play a large part in aircraft communications of the future. The time has come when telephone fittings and wiring can be conveniently incorporated in the actual design and manufacture of aeroplanes. In war time the work had to be done after the machine was in service. This necessity led to the formation in France of what might be termed a "Telephone Service Section" whose duty it was to equip squadrons and supply them with serviceable apparatus and trained personnel. After the Armistice this Section equipped the Folkestone-Cologne mail route, both ground stations and machines. Machines were flown over to the depot, and within two or three days were fitted, tested, pilots trained, and helmets fitted for head receivers. One test flight was made in which the pilot operated his own set, and if passed as proficient, he returned to his squadron. A careful check of the working of the communications was made by arranging for an inspecting officer to fly periodically up and down the route and keep a careful check on the working of the stations.

Captain H. J. Round: The author and I have worked together a good deal during the last 10 years on various wireless subjects, and we have usually been in agreement; but during the early stages of the war I have very distinct memories of many attempts on my part to divert his work because of certain difficulties and many objections I saw to wireless telephony in the air. In the main he was correct, but in one or two particular cases I still think I am right. One case I can call to mind was the question of flight control. This was, I believe, worked out very completely but never actually put into war practice. All the author's wireless telephony was done with small power, in fact large power was not possible at the time. Owing to this use of small power, the immediate answer of the enemy to

our flight-control would have been to fit their fighting flights with $\frac{1}{2}$ kw. quenched-spark jamming outfits. Our own flights, trained to manœuvre with wireless telephony, and not so well trained to visual control, would have been at once at a disadvantage and I could see no immediate technical answer to their jamming. The large organization worked out for flight control would have thus been rendered useless until a much more powerful set was evolved. Anyhow I think this particular case points every time to the use of more power whenever wireless is used in active areas, and where interception can do little harm. Peace sets are being more generously designed, and, from the standpoint that our peace sets should be as adaptable for war as possible, this is a very good point. I should like to challenge the author on his statement at the bottom of page 380, col. 1. Although both the grid and choke controls are actually very complex in action and it is difficult to say how much of any one action is coming in, grid control in the main is a method of choke control where the same valve is used both for voice magnification and for oscillation purposes. The grid control is very considerably improved by inserting an anode choke, and when this is used the power considerations are the same, and generally the aerial ammeter does not move when one is speaking. I think that, except for small sets, the days of both anode and grid control are over. In some recent work, I have gone back to the circuit of Fig. 1, one of the best methods for controlling large power with the minimum voice distortion, of course with the microphone replaced by instruments which will handle more current.

(*Communicated*): I should like to add a short historical sketch of some of the valve transmission work we did from 1913 onwards. Although the work was for the most part on telegraphy and not telephony, the apparatus involved was practically the same. In 1913–1914 we were developing a valve system of sending and receiving both telephony and continuous waves. Such a system was evolved and practical apparatus exhibited early in 1914, various patents being taken out. This work was of course developed on the lines indicated by the work of De Forest, Lieben, Reiss, Meissner, and Franklin. During this period we evolved, amongst many other things, the anode and grid control methods, and also the plain aerial method of using valve transmitters. Unfortunately, lack of vision—perhaps the thought that they were rather obvious things—prevented the grid and anode controls being patented, but I well remember that the grid control was produced as a natural evolution of the anode control because it used only one valve, and that was a very good point in the days when each valve required watching. Both methods were actually tested at Marconi House and elsewhere, and good results were obtained. The high-frequency control was also evolved, similar to the method mentioned by Mr. Turner, and this was patented. At that time, currents in the aerial so seldom exceeded 1 ampere that microphonic control was always found to give the best quality of speech and was more usually used. When the war started, other more important work stopped development for a time, and Major Prince carried on the development of our set to make it suitable for the air. During 1915 the development of the self heterodyne and the use of plain aerial circuits in reception suggested to me the revival of the plain aerial circuit which I used in 1914 for continuous-wave transmission. Urged on by the late Lieutenant Hyde Thomson, to whose brilliant imagination I should like to pay great tribute, we made up the first continuous-wave plain aerial transmitters for aeroplanes, airships, and ground stations, and, I believe, made the discovery of the extraordinary range possible with short continuous waves using self-heterodyne receivers. I will quote three cases of this. Late in 1915, Lieutenant Tomlinson, with a 20-watt continuous-wave plain aerial transmitter constructed in my laboratory, went up at Wormwood Scrubbs in a small S.S. airship, and his signals were easily received with one valve 400 miles away at Aberdeen, the wave-length being 1,200 metres. Major Binyon, flying from Eastchurch to Eastbourne in an aeroplane with the same set, was read in London with very loud signals, and the operator listening at Eastchurch reported hardly any change in strength during the complete flight of the plane. Thirdly, a similar set erected at Folkestone, with a 70 ft. aerial wire completely inside a two-story house, was read easily at Marconi House, about 60 miles away, on one valve, and was also simultaneously read at Calais. One of these sets was, I believe, actually the first continuous-wave set used in the British Army. These results can be repeated at any time as everyone knows now, but I believe they were new then. In all cases the practical details of the development were carried out by others.

Professor R. Whiddington: The apparent broadening of the wave during telephony is really fundamental and unavoidable. A slightly damped (telephone) receiving circuit, therefore, while responding to the radiation as a whole, will always select that particular frequency for which it is actually atuned. This phenomenon, while always present in some degree, is particularly marked when the radiation is weak, and in consequence the receiving circuit is worked very near the limit of reaction. In such a case as this, loud speech may be obtained, but distorted to such an extent perhaps as to be unintelligible. An interesting experiment, and one easy to carry out, affording a practical demonstration of these multiple waves, is to analyse by an ordinary wave-meter the radiation from a valve oscillating-circuit using an alternator as the source of power. The carrier wave is then modulated according to the frequency of the alternator and the wave-meter detects at least two frequencies on either side of that corresponding to the radiating circuit, the frequency difference depending on the period of the alternator. Mr. Turner has referred to the possibilities of the "dead aerial" system in wireless telephony, the system in which the carrier wave only comes into action when the voice affects the microphone. During the war I carried out experiments resulting, I believe, in the first successful two-way telephony along these lines.

Captain P. P. Eckersley: It should, I think, be realized by those who have read this paper that the achievement of bringing the aircraft telephone to its present state of perfection has been a problem of pro-

paganda as well as a technical one. Whereas early in 1915 the average pilot looked upon all wireless on machines as "another gadget," in 1919 certain pilots on the postal routes refused to fly without a wireless telephone. On the technical side the introduction of remote control, the simplicity of the adjustments, and the lightness of the apparatus have all helped to convince the non-technical users of the possibilities of the apparatus, and for war purposes it is difficult to see how the sets could have been bettered. On pages 377 and 378 the author records how spoken messages at St. Omer were heard 100 miles away, the transmitting aerial current being only 0·25 ampere. The wave-length used was 300 metres, and this largely explains how such a remarkable range was obtained. The standard R.A.F. set used 450 metres and an aerial current of 0·4 ampere, and in the Cologne postal route gave remarkable ranges. It seems therefore, from a study of these results, that short wave-lengths are very desirable for aeroplane telephony. The International Air Convention has, however, legislated that the aircraft wave shall be 900 metres, a rather retrograde step when it is realized that the resistance of an aeroplane aerial is high in any case. Even though we are allowed five times the power of the author's set, this is therefore not being utilized to anything like its best efficiency, since the radiation resistance is cut down many times and introduces further problems in winding high-inductance aerial coils which necessarily militate against efficiency. Jamming is of course a factor to be very seriously considered, but if free æther could be sought among the lower wave-lengths the designers of modern aircraft gear would be less hampered and could for the same ranges construct lighter apparatus. On pages 378 and 379 the author refers to methods of modulation and discusses them in relation to the receiver. I think the designers were very happy in their choice of the choke control, as it gives an ideal and stable method of control. What perhaps is not sufficiently emphasized in the paper is the fact that choke control uses the power available in the carrier wave to a maximum. That is to say, it controls the intensity of the antenna current not only below the line of constant output but above it. Any control which merely reduces output must on the face of it be less efficient than one that both increases and decreases it. Neglecting therefore the power absorbed in the control valve, the wave-length change and the bad regulation of the choke transformer, one would expect the current change apprehended by the detector to be twice as great with choke control as with, say, grid control. Mr. Turner has referred to choke control, and has said that the method is wasteful of power. I do not think that is truly so, because, when it absorbs power, that power is stored up in the choke and is released afterwards, being analogous to a vibrating pendulum. I think the circuit that Mr. Turner described is a very old one and very well known. Captain Round used it with considerable success, and in America I believe it is very largely used. Professor Whiddington referred to the quiescent aerial system. I think one of the troubles about this system at present is that it gives very poor speech. I do not think much has been gained, even if the quiescent aerial system is successful, the problems of receiver protection still remaining. Speech quality with the choke control was, I think, very good, but it becomes increasingly apparent that the characteristics of the receiver influence speech quality nearly as much as the circuits of the transmitter. This is brought out on page 379, where the author points out that by pushing reaction to its limits freak results are obtained. Reaction on the receiver, although tending to raise the intensity, certainly distorts speech at times. This may be due to the narrow resonance curves excluding essential frequencies in the received waves, or again may be produced in the detector valve by intensifying the carrier wave so that "wipe out" is produced. The consequent distortion may be rectified by mistuning, but this quality of the largely reactioned receiver is not a good one as it makes two adjustments mutually interdependent, a bad quality for pilot-operated sets. Thus the line of development is indicated in the author's concluding remarks, where he points out that the latest types of receiver employ high-frequency magnification which makes intense reaction less necessary for a given range and so gives two independent adjustments, signal intensity and tuning, both of which should not greatly interfere with quality. Those who have had much experience with telephony have perhaps been sometimes worried by "breaking" of speech, as the author points out on page 378 in connection with one experimental circuit. Such breaking can sometimes occur even with choke control, although it is less susceptible to this trouble. This is, I think, bound up with the oscillating circuits and particularly the position of the mean grid volts line on the oscillating valve. There are broadly two possible states of oscillation bound up with the mean grid volts, one the trigger condition where the oscillation dies suddenly when the reaction is reduced, and the other condition where a lingering death occurs. In the sudden death or trigger condition, it is possible if the reaction is on the weak side to get broken speech. In the other condition I have never noticed this tendency, and even the substitution of a coarsely adjusted buzzer for the microphone will not stop the system oscillating. Where it is not possible then to over-control and get breaking speech, it is advantageous sometimes to introduce a second magnifying valve. This has a particular application where weak land-line speech has to be relayed on to a wireless system, but pays even where a voice is speaking directly into the telephone. The author has skimmed over the thin ice of magneto noise, and those who have done much air work sometimes wish they could dismiss the subject as lightly. The problem is very acute, first from its very nature and, secondly, because it is next to impossible to experiment in the air. It is useless to do much on the ground, and once in the air arrayed in a heavy flying coat, a tangle of wires round one's feet, a few suspended swaying boxes dotted about round an already cramped cockpit, and a pilot who wants to go home, coherent thought becomes almost impossible. Results, so far, have been obtained by avoiding machines that were notoriously noisy, but much remains to be done. Shielding can in many cases be carried out *ad nauseam* without any diminution of the noise, whereas some small, apparently foolish,

change in the connections produces the longed-for peace.

Mr. L. B. Turner: The author has devoted some attention to the system of choke control embodied in the very elegant telephone transmitter of his design, and he seems to suggest there is some degree of mystery as to how it functions. Referring to Fig. 3, when the voice raises the grid potential of C, the anode tries, as it were, to suck in extra current; but as choke L keeps the high-tension battery current more or less constant, the top end of L falls in potential, and C is supplied only at the expense of P. There is thus no optimum value for the inductance of L; the larger it is the better, but when once its impedance is very large compared with the mean anode resistance of P, nothing is to be gained by making it larger. The author reports that at 750 periods per second an inductance of 5 henries was nearly as good as any higher value. The reactance of this inductance at this frequency is $2\pi \times 750 \times 5 = 24{,}000$ ohms. This, being already large compared with (say) 5,000 ohms as the anode resistance of the oscillating valve, is nearly as good as an indefinitely

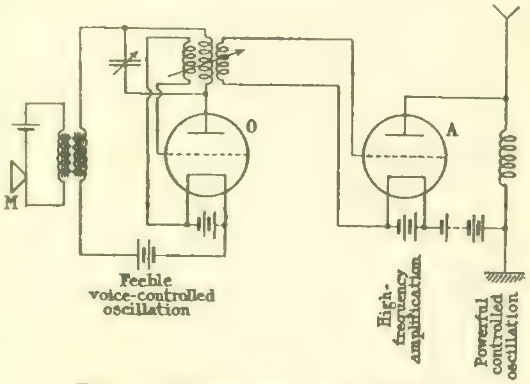


FIG. A.—Wireless telephone transmitter.

great inductance. As the author points out, the choke control has many virtues; but I think he gives a wrong impression when he says (see page 380, column 1) that "although the control valve does not appear at first sight to contribute to the output, it actually does so." The control valve varies its mean consumption with alternate gulps and vomits of electricity according to the microphone stimulus on its grid; but the mean power of the high-frequency oscillation is not affected by it. On the other hand, the control valve consumes a steady mean power, which is sheer waste from the point of view of efficiency as the ratio between output and input powers. In small aircraft transmitters, this is not of much significance; but with these circuits, as the antenna power is increased, so, *pari passu*, must the power wasted in the control valve be increased. With the primary object of avoiding this waste, Captain R. H. Wagner and myself devised the type of telephone transmitter shown in principle in Fig. A herewith. Here O is a feeble oscillator controlled in amplitude by the microphone M, and A is a single or multi-valve amplifier inserted between O and the antenna. Thus, however powerful the transmitter, the microphone has to modulate only a feeble oscillation, the modulated oscillation being subsequently amplified to any desired extent. An incidental advantage of this arrangement is that it reduces the difficulty of attaining both-way telephony referred to in the paper. For both-way telephony, the oscillator, or at any rate the antenna, must oscillate only while the voice is agitating the microphone; and the feebler the oscillator, the more easily is this accomplished without loss of articulation. In conclusion, I wish to refer to another point respecting modulation by the voice, not specifically mentioned in the paper, although I think it was the author who first brought it to my notice during one of those stimulating friendly discussions in which at one period during the war he and I and our colleagues used to indulge. When there is a large unmodulated residuum in the transmitted oscillation, the uncontrolled portion may yet be of some service at the receiver in maintaining good rectifier efficiency for very weak signals, as in the case of heterodyne reception. But this is a very uneconomical way of obtaining the augmented detector efficiency, since precisely the same result can be produced more completely by an independent heterodyne at the receiver, tuned dead-on so as to produce no beat-note. This kind of zero-beat heterodyne reception is of great value in telephony, and does not seem to have received the attention it deserves.

Major T. Vincent Smith: The sight of that old piece of apparatus calls back to my mind the early days at St. Omer when the author and Captain McDougald came over to show us what they had done in the way of wireless telephony. We tried it in all manner of ways, and so long as it was in capable hands it never showed any signs of failure. I also remember very forcibly Lord Kitchener's expression when he put the telephones on, rather unwillingly at first, and began repeating every word that Captain McDougald was saying. He said afterwards that it was one of the most interesting things he had seen on that visit of his to France. I also remember the panic that ensued at Headquarters when information was sent over from Lowestoft that every word had been heard there. It stopped our experiments for quite a long time, because the Intelligence Staff thought that the enemy would get valuable information from our messages. However, when that restriction was withdrawn by Headquarters there was obviously a lot of spade work to be done before we could apply wireless telephony to anything like practical use in the line, and I pay full tribute to the author, Major Orme, and everybody associated with them for the way in which they met essential suggestions regarding the simplification of the apparatus. The design of aircraft wireless apparatus for war use is profoundly modified by the personnel who have to use it, and I am glad to see that the author acknowledges those difficulties which I had to face, and which forced me to insist on simplification of design, and this I am bound to say he was always able to meet. The main point about the apparatus was: what was it to be used for? It was most inadvisable to show an article like a wireless telephone to the Higher Command, who imagined that one had only to have a telephone without

wires in order to solve all communication difficulties; whereas, of course, it was our duty to modify their enthusiasm considerably, otherwise they were inclined to ask us to do all sorts of impossible things. Although at first sight it might appear to be a useful substitute for the ordinary transmitting key, I am rather doubtful whether, except in certain cases, it is desirable to do away with Morse. I am convinced, it spite of what Captain Round said, that there is one extremely important application of the wireless telephone, and that is inter-machine telephony for the purpose of regulating a formation flight. I think it is the most important use to which the wireless telephone can be put. The question of jamming, I agree, is very important, but, after all, we had to deal with that along the whole of the Western Front. The Germans never succeeded in jamming us to any serious extent. I think it is a sign of inferiority to have to jam one's opponent, and we were always proud of the fact that we did not need to jam them.

Mr. H. M. Dowsett: I would ask the author whether the first working set—as distinct from the skeleton model made up at Brooklands on which speech was first received—was not made up at the Marconi works under the supervision of Captain McDougald. With regard to the choke control, it is interesting to record that early in 1914, in tests which were carried out by Captain Round between Chelmsford and the author's house at Danbury, a choke was used in the anode circuit of the oscillating valve which had the same function as the choke in the R.A.F. circuit, although it behaved less efficiently, as the modulation control was exercised through the grid circuit of the same valve instead of by means of a separate valve acting on the choke direct. I should like to know the author's reason for advocating the filtering out of the lower speech frequencies. Unless the valve, the method of control, or the microphone unduly favour such frequencies and the suggestion is put forward as a means of correcting this, it is not obvious why the distortion which must result, and which must impart a squeaky character to the speech, is likely to be an improvement. It is well known that the higher harmonics are of great importance, and a voice with a high pitch is much more effective than one with a low, but does it follow that high-pitch speech would be still more effective with the lower frequencies removed? The necessity of heavily damping the diaphragm of the microphone in order to render it less sensitive to noise is one of those measures which it may be hoped will in time be rendered unnecessary. The baffle mouthpiece so far has not proved a success, but should it do so the more sensitive ground microphone could be used in the air with advantage. The selection of suitable materials for the diaphragm, as pointed out by Captain Furnival, may help considerably towards the solution of this problem. There appears to be no technical reason why the perfectly silent direct-current generator looked forward to by the author, which can be used for the high-tension supply of both the transmitting and the receiving valves, should not materialize at the present time. Generator noises are due partly to commutation and partly to field distortion by the armature teeth. By means of interpoles and properly designed brushes and brush-gear the commutation can be rendered sparkless; and by suitably slotting the poles so that when one conductor of a coil is opposite a tooth, say in a north pole, the other conductor of the same coil is opposite a slot in a south pole, equal and opposite harmonic electromotive forces will be generated in the winding and will neutralize each other. The waveform of the terminal electromotive force will then depend solely on the shape of the poles and the arrangement of the armature coils, both of which are controllable, so that it should be quite possible to obtain an unvarying direct-current voltage.

Flight-Lieutenant L. A. McDougald: This paper gives a very comprehensive account of the development of aircraft wireless telephony during the war. A very considerable part of our work consisted in reducing the size and weight of apparatus, and of increasing its efficiency and simplicity of operation. The first experimental transmitter, of an earlier design than that shown in Fig. 1, had six adjustments, many of them critical. The final 20-watt set, as pointed out in the paper, required no adjustment. The soft valves in use in the early days were provided with a regulating device in the form of a pip containing a crystal of asbestos or other mineral. This, when heated, reduced the vacuum in the valve. It was the custom to heat the pip before a flight took place, but it often happened that when in the air one found the valve had become too hard to oscillate. In order to overcome the danger of applying a naked light, a small electric heater was devised which could be placed over the regulating pip. It is worthy of note that during the demonstration flight for the late Lord Kitchener a snowstorm was in progress. In consequence we could only fly at a height of a few hundred feet, and the fact that our speech was picked up by Lowestoft is therefore all the more remarkable. The trailing aerial always lends itself to variations of wave-length when the aeroplane is manœuvring, due to change of aerial shape. This difficulty is overcome by the use of the so-called "fixed aerial"—that is to say, an aerial rigidly fixed inside the wings and fuselage of the machine, from which it is thoroughly insulated. Dr. Whiddington has pointed out elsewhere (*Nature*, vol. 104, p. 630) that this wave-length change is due in part to a variation of anode voltage consequent on the changing speed of the wind-driven direct-current generator during a manœuvre. With a modern, well-regulated, wind-driven generator, I think the greater part of the change in wave-length is due to the change in shape of the trailing aerial. This is borne out by the fact that the effect was very noticeable with the original telephone transmitter, the source of anode voltage being a 600-volt dry battery. Very promising results have been obtained on fixed aerials for reception. Using the 20-watt transmitter and the R.A.F. Type-X five-valve receiver-amplifier, an "all-round" range of 3 miles and a "best position" range of 7 miles have been obtained. These ranges are not the limit for the reception of intelligible speech, but were considered to be safe working ranges. By "best position" is meant the best relative position of the two aeroplanes. Magneto noise is generally

more troublesome with a fixed aerial than with the trailing aerial, but it can be successfully eliminated by using high-tension cable covered with a flexible metallic braiding for all the magneto circuits. The metallic braid is " earthed " to the frame of the aeroplane at frequent intervals.

Mr. F. P. Swann : The author and several speakers have referred to the fact that on the occasion of the wireless telephone demonstration at St. Omer in 1916, the speech was heard at Lowestoft. I am quite sure the author will not think that I am trying to detract from the merits of his set if I suggest that a certain amount of the credit should be given to Lowestoft. This station was installed with the most sensitive receiving gear then known, and was doubtless responsible for a generous portion of the range covered.

Major C. E. Prince (*in reply*) : As I mentioned in reading the paper, I had not intended to get into such deep waters as wireless telephony in the abstract, and confined myself to the practical application of it with which I was identified, simply because the whole subject was too wide to cover. Many of the points raised will, I hope, be touched on and extended in the discussion on Captain Eckersley's paper on " Duplex Wireless Telephony," and will, perhaps, be more germane to that subject than to my paper.

Some of Mr. Turner's remarks have already been answered for me by Captain Eckersley. On one point he seems to have misunderstood me. If he will read the paper carefully he will see that I never implied that there was any critical value for the choke ; only that a certain minimum value is necessary, after which it becomes the equivalent of one indefinitely great. So that we really seem in complete agreement. I believe that he has fallen into an error in his treatment of the contribution of the control valve to the output. Or rather, while right about the action of this valve—whose effect on the total output is virtually to make the mean value remain equal to the normal unmodulated output of the oscillator—he seems to have forgotten that when one valve only is in operation the mean output will be something considerably less than the above steady output. All this quite apart from considerations of the maximum instantaneous excursions, on which, after all, modulation depends. The amount of steady anode current consumed in this valve when not in operation is a local question depending on grid mesh, and so on, and can be quite negligible. Taken in conjunction with what Captain Eckersley has pointed out, I think that this justifies the assertion that the control valve does make its due contribution to the telephonic or modulated output.

With reference to Professor Whiddington's remarks, I owe him a debt of gratitude for first clearing my ideas on this subject, some years ago. A radio frequency modulated or supplied at another, say, sound frequency, will give a group or family of waves of which the resonance curve will appear as a central (" carrier ") wave accompanied on each side by a series of diminishing intensity, like the Crusader on the old memorial brasses surrounded by his family. It is quite plain that this is a mathematical necessity, and that consequently during speech the radiation is in the form of a constantly changing broad band or " spectrum " of waves, though it should be remembered that the subsidiary waves, being weaker, tend to disappear, and at great distances the " spectrum " narrows again till practically only the principal wave remains. But in alluding to the change of wave-length so far inseparable from all known means of modulation, I did not intend to refer to this phenomena, far less to controvert it, but rather to the slight change of frequency of the oscillator, that is of the carrier wave or central point of this spectrum. In telephony, as I visualize it, not only is this spectrum in itself compounded of the various spectra, each derived from a definite audio-frequency, fundamental or harmonic, but it is constantly changing with each speech sound ; and, with its centre or " Crusader " wave, is also subject to a general fluctuation round about its normal unmodulated frequency, so that it is really a very complex matter indeed. In any case the principal difficulty of all wireless telephony is the means of modulation, and any contributions ought to be welcomed, because we cannot know too much about it. As regards Dr. Whiddington's reference to the dead or " quiescent aerial " system, his independent re-discovery of this corollary of choke-control filled us with great hopes, and it was no small disappointment to find that it had already been patented in America, and also to discover certain inherent defects which militated against speech-quality. This will no doubt come under consideration in Captain Eckersley's paper on " Duplex Wireless Telephony." At the same time I cannot help but consider it as the foundation of the probable future duplex system.

Major Vincent Smith has spoken about the simplification of the sets. It was due to him, very largely, that we were forced, much against our will, to simplify to the extreme. It is very largely because he made us " dance in chains " that we succeeded in arriving at this great simplicity, which meant all the difference between success and failure. He has referred to what may be called the mental or spiritual difficulties of the introduction of telephony in aircraft. We knew them too well, and only an unwavering faith in its possibilities in the most definitely difficult and unpromising field enabled us to see the victory of the spoken word. On behalf of those who worked with me, I should like to thank him for the kind things he has said about us.

I do not think that Captain Eckersley's or Captain Furnival's interesting remarks call for any comment by me.

Answering Captain Round, I am extremely glad that he has raised the historical side, because I am conscious that the text of my paper does not make clear, as it should, that while the novelty lay in their unprecedented application, the transmitting circuits employed in the apparatus I described were all reproductions of, or founded upon, those developed before the war by himself and his assistants. Before the war they had brought the small-power valve wireless telephone to a remarkably high state of development, and in June, 1914, demonstrations employing various circuits had been given between my house and the Marconi works, to representatives of the Army, Navy, and Post Office, so that in attacking the subject of aeroplane telephone

working the circuits and system were already at hand, and the problem was that of applying them to the novel conditions. Thus the first aeroplane transmitting set (Fig. 1) employed bodily his coupled circuit arrangement and was a direct adaptation of the ground set demonstrated by the Marconi Company in 1914. The great advance made by Captain Round by the "plain aerial" system of excitation for continuous waves was what gave the impetus to the search for a satisfactory method of applying voice modulations to such a circuit, and when, in the course of my experimenting, the problem was submitted to him, he came to the conclusion that a modification of one of his 1914 anode control circuits would be the most suitable; and, after some confirmatory experiments at Marconi House, gave me on 5th May, 1917, a sketch of the choke control circuit described, which was embodied in the Mark II transmitting set. It was afterwards found that the same idea was set forth in an American patent specification of the General Electric Company of America, and when the American Signal Corps brought over some specimen apparatus in 1918 it was found to be employing a system of modulation similar to that of our service instrument. I may say that, apart from the origination of the circuits, Captain Round's continual advice and help were of the greatest possible assistance also throughout the course of development. Turning to his remarks about grid and anode control, this opens up many interesting considerations of the exact relationship of his 1914 circuit (having the microphone transformer in the grid circuit, and a choke in the anode supply) with the later two-valve development. I agree that it seems correct to consider the former as essentially a choke control system, though with one valve only, and it was, I believe, recognized by him as such at the time. Where, however, no such choke is inserted, i.e. there is plain grid control, I would be inclined to think that there was an essential difference between the two arrangements: (1) where the anode is kept at a fixed potential by an unlimited source of current supplied through a negligible impedance, while the electrification of the grid was varied; and (2) where the latter was constant (except in so far as it was affected through the reaction coupling) and the potential of the anode varied. The actions must, however, as Captain Round suggests, be very complex. The title "choke control" has now, however, passed into common parlance as descriptive of the particular two-valve arrangement shown in Fig. 3.

Mr. Dowsett will, I trust, find many of his remarks answered by what I have just said. The first or Mark I set was made from my designs as he describes. The filtering out of lower speech frequencies was only suggested by me as a possible correction to be applied in cases where the latter might be unduly favoured. Human thought (in English) is principally conveyed through the consonants and higher harmonics, and squeaky speech, though unlovely, is intelligible; whereas speech in which only the lower frequencies exist conveys no meaning. When intelligibility is of the greatest importance, it might be worth while to exaggerate the frequencies on which it depends. It was merely a suggestion. The making of a microphone to work satisfactorily in extreme noise is, of course, one of the greatest difficulties of aeroplane work, and so far as our interminable experiments showed, all devices to reduce the external noise are merely changes rung on the theme of general insensitiveness. The best hope for improvement lies in quieter machines; and already civil aircraft are proving better in this respect than the fighting aeroplanes we had to equip. Mr. Dowsett is right in pointing out that it is by no means impossible at present to produce a generator quiet as regards ripple, or "telephonically silent." But this is only half the problem. There are generally high-frequency disturbances (akin to magneto noise) set up, mainly by sparking at the brushes, which are a still more serious difficulty where high-frequency magnification is employed. However, there seems good hope of finally conquering both difficulties, even with large magnification.

Mr. Swann has referred to the occasion on which speech with 0·2 ampere aerial current was picked up at Lowestoft from St. Omer. This was undoubtedly a magnificent achievement in reception, by a station equipped by Captain Round with the most efficient possible apparatus. My reference to it, however, was not meant to involve any estimate of the merits of either transmitter or receiver, but merely to point the moral of the efficiency of radiation of the shorter wave then in use.

THE POULSEN SYSTEM OF RADIOTELEGRAPHY
HISTORY OF DEVELOPMENT OF ARC METHODS

C[harles] F. Elwell

The Poulsen System of Radiotelegraphy.

History of Development of Arc Methods.

By C. F. ELWELL, E.E., Fell.I.R.E., M.I.E.E., M.Am.I.E.E.

As is well known, the Poulsen arc system of radiotelegraphy employing undamped waves was invented by Dr. Valdemar Poulsen and Prof. P. O. Pedersen, of Copenhagen, Denmark, in 1902, when the various damped wave or spark systems were still struggling with the many problems inherent in the use of damped waves. Although the Poulsen arc system showed great promise, and was greeted with many prophecies as to its future value, it made very little real progress until 1909.

History of Early Work.

The period prior to 1909 was characterised by much slow plodding work in Denmark, during which the stations at Esjberg and Lyngby, 180 miles apart, form the chief examples of what was done. The use of these stations for demonstrations to Cullercoats, in England, brought the possibilities of the system well to the front.

An English company was then formed, which erected what at that time was an ambitious project at Knockroe, in Ireland. Three masts, each 360 ft. in height, were put up; but, owing to their fragile design, they were soon reduced in height. A 30 kw. arc generator was installed, and tests were carried out with Denmark. This company became involved financially, and further development of this very promising system was deferred until a later date.

American and German Recognition.

The possibilities of using undamped waves, as developed by a small Poulsen arc in hydrogen, for wireless telephony were recognised by Dr. de Forest in America, and he developed a small compact set for wireless telephony, of which some 28 were purchased and installed in the U.S. Navy in about 1908.

The Germans early recognised the inherent value of undamped waves in general and the arc method of production in particular. After many attempts to develop a system in which Poulsen's basic invention of the use of hydrogen could be avoided, the rights for Austria and Germany of the Poulsen arc patents were purchased. It is significant to note that, even at this time, the chief development work carried out by the Germans and Austrians was on field sets for military purposes. (*See* Fig.1.)

It seems strange that the German engineers never developed the arc generator in the larger sizes, and even during the war, when material and labour were at a premium, no larger sizes were constructed.

The Poulsen Arc for Short Distance Work.

In 1909 the writer became convinced of the possibilities for development of the Poulsen arc system for long-distance radiotelegraphy. After having witnessed some demonstrations (at this time there were no commercially operated installations) between the before-mentioned Esbjerg and Lyngby stations and Copenhagen, he made arrangements for the purchase of the exclusive rights to the Poulsen system for the U.S.A. An American company was formed, and two sets (one 5 kw. and one 12 kw.) were purchased from the Danish parent company. Stations were erected at Stockton and Sacramento, two cities in California, the distance between them being 50 miles. These stations were each very similar to the station at Lyngby, in that they consisted of two 180 ft. masts carrying a double cone antenna suspended from a steel cable between the two masts. Demonstrations of wireless telegraphy, both hand speed and auto-

matically transmitted and received high speed, and of pure articulate wireless telephony were made

Criticism was raised that two stations might work very well together, but that the advent of a third station within the range of the first two would surely be impossible. Ample proof of the impossibility of disturbing communications carried out by means of undamped waves was afforded at this time by near-by spark, or damped wave stations, which did their best to jam the interloping system, and unwittingly furnished the best advertisement to the newly budding system. In 1910 the third station was built at San Francisco, and consisted of two 300 ft. wooden lattice towers, designed and built by the writer. These towers were the forerunners of 50 similar towers which have been built, ranging in height up to 714 ft.

Fig. 1.—Poulsen Field Set.

The San Francisco Station.

The San Francisco arc generator was manufactured in San Francisco by the American company along the lines of the generators purchased in Denmark; but improvements were made in order to permit the use of the arc generators for long periods without over-heating the coils, fusing the anode, &c., as it was intended, and all development work was to that end, that these stations should be used in commercial work in competition with the wire lines.

Between the three stations at Stockton, Sacramento and San Francisco ample demonstration was made of the close tuning, ability to rapidly change the transmitted wave-length, absence of interference, simplicity and ease of working of the apparatus, diminished interference from atmospherics, &c.; in fact, the advantages of the system over the spark or damped wave systems then in use.

The Honolulu Station.

From this moment the technical and commercial progress of the company was rapid. Stations were built in Los Angeles, El Paso, Kansas City, Chicago, Portland and many other American cities, and, as these stations were used in commercial work in competition with the wire lines, much valuable development work had to be done by the American company in order to make the arc generators and its accessories reliable. In 1912 a second station was built in San Francisco and a new one in Honolulu. As these stations were the subject of comment in Lord Parker's Committee report, a brief description would not be out of place at this juncture.

The antenna consisted of what is known as a double cone antenna, and was attached to a steel cable 600 ft. long suspended between two wooden lattice towers each 440 ft. in height. (*See* Fig. 2.) The generator consisted of a 30 kw. arc generator, and the compactness of the apparatus can be gathered from the view of the wireless room at Honolulu shown in Fig. 3.

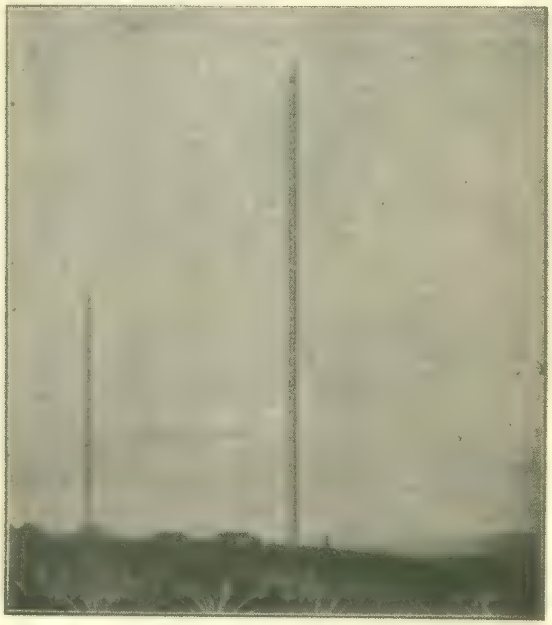


Fig. 2.—Masts at Honolulu Station.

The power plant at Honolulu consisted of a 60 h.p. Union oil engine driving two 14 kw. Westinghouse direct-current 500-volt generators operated in parallel. A second engine was installed later. Although the distance was 2,400 statute miles, these two stations communicated with one another continuously from their inception in 1912.

Development of a Press Service.

The effect of these pioneer long-distance stations on the life of the people of these islands can be gathered from the fact that a

Fig. 3.—Wireless Room at Honolulu

press service of a guaranteed minimum of 1,500 words per diem was immediately entered into with the "Honolulu Advertiser," at a rate of about two cents per word; whereas, up to the advent of the wireless, the readers of this newspaper had to be content with from 80 to 120 words per diem about the world's happenings of chief interest and importance. These words transmitted by the cable from San Francisco cost 16 cents a word. The islanders paid 35 cents a word for their cables to San Francisco, which the wireless company promptly reduced to 25 cents, and a large business was promptly built up, as the cable company, by letting the wireless company do the San Francisco–Honolulu business, was enabled to handle more traffic to the Phillipines and Japan at a very lucrative rate.

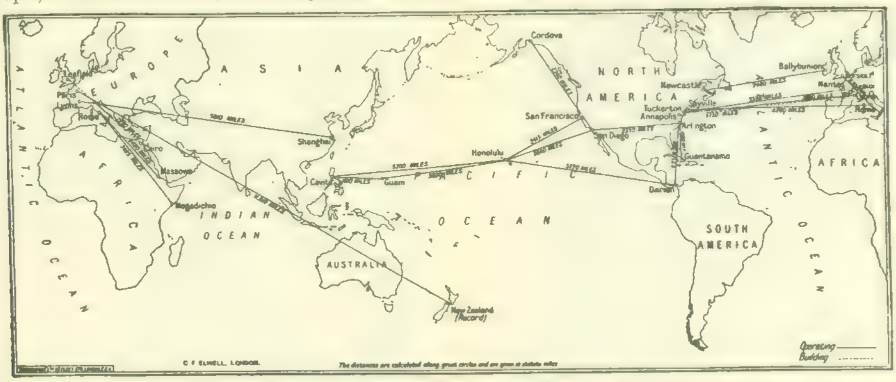


FIG. 4.—SHOWING POULSEN ARC SERVICES.

THE ARLINGTON STATION.

The next step in the development was the installation of a similar 30 kw. arc to that used at San Francisco and Honolulu in the U.S. Naval station at Arlington, near Washington. This station was at that time the finest station in the world. Its antenna consisted of three self-supporting steel towers, of which two were 450 ft. in length and one 600 ft.

A Fessenden 100 kw. damped-wave set was installed, and gave about 108 amperes in the antenna. The arrival of the 30 kw. arc gave an opportunity for comparative tests of the value of undamped waves versus damped waves. Although the arc set was only rated 30 kw., it gave 54 amperes in the antenna. Tests of the strength of the received signals were carried out at various stations. At distances of a few hundred miles the strength of the received signals was proportional to the energy transmitted which was proportional to the square of the antenna currents. This showed that the question of absorption does not become apparent until transmission over greater distances be involved. The final tests to Colon, on the Isthmus of Panama, a distance of 1,800 nautical miles, resulted in a clean victory for the 30 kw. arc over the 100 kw. spark set. In addition, the arc set corresponded with San Francisco and Honolulu, a distance of upwards of 5,000 miles. The results of these tests, and others made with the same 30 kw. installation, was the adoption by the U.S. Navy of the Poulsen arc system, and the ordering in 1913 of a 100 kw. set for installation in their station at Darien, on the Isthmus of Panama. This station has three towers each 600 ft. high.

From June, 1913, the development work in the U.S.A. was continued by the Federal Telegraph Company's engineers, under the direction of L. F. Fuller, and the many large arc sets now in use by the U.S. Navy are the result of this development. The U.S. Navy has at the present time 10 high-power (more than 100 kw. input) arc stations in operation over distances of from 1,600 to 5,300 miles. (*See* Fig. 4, which shows the principal high-power Poulsen arc stations)

DEVELOPMENTS IN THE BRITISH ISLES.

The writer came to England in 1913 as chief engineer of an English syndicate formed to purchase the Poulsen and Pedersen patent rights for practically the whole world. This syndicate had planned and was erecting transatlantic stations at Ballybunion on the west coast of Ireland and Newcastle, New Brunswick, Canada. Each of these stations had an umbrella type antenna in six sections supported by a central mast 492 ft. high, and surrounded by six masts each of 300 ft. Two 100 kw. arc generators, designed and manufactured in Copenhagen, were installed at Newcastle, and one 100 kw. and one 200 kw. arc generators were installed at Bullybunion. The maximum antenna current obtained was 110 amperes, with an input of 130 kw. Communication was established across the Atlantic towards the end of 1914, and in the early days of the war the stations were used to a small extent. The syndicate did not exercise its option to purchase the Poulsen and Pedersen patent rights, and a new company was formed to take up these rights, and it purchased the assets of the syndicate.

SOME RECENT STATIONS.

Towards the end of 1913 a contract was awarded to the syndicate for the erection of a complete 100 kw. Poulsen arc station designed by the writer for Horsea Island, Portsmouth, the antenna, triangular in shape, being suspended from three wooden lattice towers each 440 ft. high. During the war a hydroplane collided with one of these towers at a height of 356 ft., and became wedged in the mast. The pilot was rescued by one of the sailors attached to the station. Fig. 5 shows the avion in the mast. The arc set is rated at 100 kw. input, and is of British manufacture. This station was completed and handed over to the Admiralty in July, 1914. It was largely used during the war to keep in touch with the fleet, and greatly exceeded its guaranteed range of 1,500 miles.

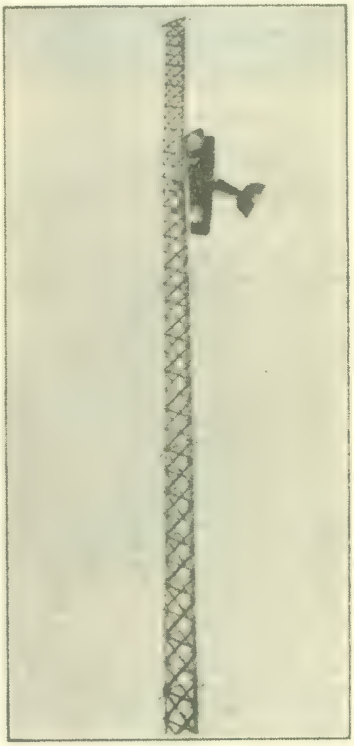


FIG. 5.—VIEW OF HORSEA ISLAND MASTS WITH SEAPLANE LODGED AFTER COLLISION.

In 1915 a similar arc set to the one at Horsea Island was installed in the Eiffel Tower, the antenna at the Eiffel Tower consisting of six steel wires attached to the tower itself. The capacity is low for an arc set of this size, which, not using a condenser, depends largely upon the capacity of the antenna. The set gave 110 amperes in the antenna. It was later superseded by a new installation similar to that illustrated in Fig. 7, which gave 130 amperes in the antenna.

In 1916 the Lyons station of the French Army was equipped with a 200 kw. arc set, which can be seen in Fig. 6. The antenna at this time consisted of eight steel masts, each 394 ft. high, forming a long narrow flat top antenna of large capacity. Upwards of 250 amperes were obtained in this antenna, and good communication was obtained with the U.S.A. with 200 amperes in the antenna.

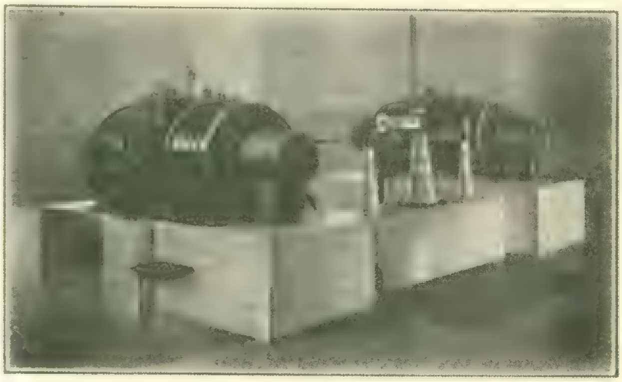


Fig 6.—Poulsen Arc Converters at Lyons.

In 1917 the Rome station was built for the Italian Navy, the antenna (Fig. 7) being suspended from three wooden lattice towers each 714 ft. in height, arranged as an equilateral triangle with 1,000 ft. sides. The capacity of this antenna, due to the masts being of wood, is low; but the effective height is high. The current in the antenna from a 200 kw. arc generator is upwards of 180 amperes, and good communication is obtained with the U.S.A., a distance of 4,300 miles.

Fig. 7.—The Duplicate Poulsen-Arc Equipment at the Rome Radio Station of the Italian Navy.

In 1917 the French Navy also built a station at Nantes, the antenna being suspended from six steel towers, each of 590 ft. in height. The 200 kw. arc generator installation at this station is similar to that shown in Fig. 7. The original 100 kw. set from the Eiffel Tower was also installed at a temporary measure.

In 1919 the towers supporting the antenna at Lyons were modified. Six of the 394 ft. towers were raised to a height of 590 ft., and two new towers each of 656 ft. were erected. A new 350 kw. arc set was installed, and gave 315 amperes in the antenna. Much better signals are received in the U.S.A., and a nightly press service is sent to Shanghai and Japan, a distance of 5,800 miles.

For the year 1920 the high-power arc-equipped stations will be represented by the installation of 250 kw. arc generators in the Leafield and Abu Zabal stations of the British Post Office. A commercial system of high-speed transmission will be installed in these two stations, which will be inaugurated later in the year.

The foregoing brief outline shows that the Poulsen arc system is to-day doing a great deal of the world's long-distance wireless telegraphy. It should be pointed out that nothing has been said of smaller powered sets of from 5 kw. to 25 kw. input, of which there are well over 1,000 in existence to-day, and the vast majority of which have been designed and manufactured in Great Britain.

THE AUDION–ITS ACTION AND SOME RECENT APPLICATIONS

Parts 1-3

Lee de Forest

The Audion—Its Action and Some Recent Applications

By LEE De FOREST, Ph.D., Sc. D.

Part I

A historical paper of unusual interest to the Radio fraternity

ANALOGIES are apt to be interesting, and in scientific matters frequently instructive and clarifying. The title of this paper, "The Audion," suggestive of *Sound*, prompts the consideration of an analogy in the realm of *Sight*—the microscope. The audion, in a measure, is to the sense of sound what the microscope is to that of sight. But it is more than a magnifier of minute sounds, electrically translated; the audion magnifies and translates into sensation electric energies whose very existence as well as form and frequency, would but for it remain utterly unknown. As the microscope has opened to man new worlds of revelation, studies of structure and life manifestations of natural processes and chemical reactions whose knowledge has proven of inestimable value thru the past three generations, so the audion, like the lens exploring a region of electro-magnetic vibrations but of a very different order of wavelength, has during the scant thirteen years of its history opened fields of research, wrought lines of useful achievement, which may not unfairly be compared with the benefits from that old prototype and magnifier of light waves. But when the first steps were taken in the work, which eventually resulted in the audion of today, I no more foresaw the future possibilities than did the ancient who first observed magnification thru a drop of water realize the present application of the high-power microscope to bacteriology.

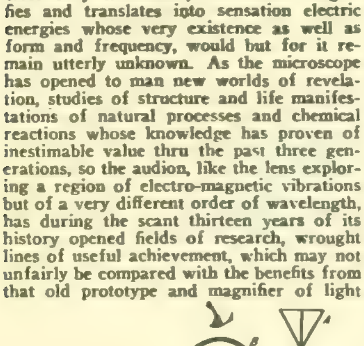


Fig 2

"What I Had Already Found in the Fl. me Detector I Now Saw It in a More Stable and Practical Form."

In 1900, while experimenting with an electrolytic detector for wireless signals, it was my luck to be working by the light of a Welbach burner. That light dimmed and brightened again as my little spark transmitter was operated. The elation over this startling discovery outlasted my disappointment when I proved that the unusual effect observed was merely acoustic and not electric. The illusion had served its purpose. I had become convinced that in gases enveloping an incandescent electrode resided latent forces, or unrealized phenomena, which could be utilized in a detector of Hertzien oscillations far more delicate and sensitive than any known form of detecting device.

The first "commercial" audion, as it originally appeared in 1906, was therefore no accident, or sudden inspiration. For failing to find in an incandescent mantel the genuine effect of response to electrical vibrations I next explored the Bunsen burner flame, using two platinum electrodes held close together in the flame, with an outside circuit containing a battery of some 18 volts and a telephone receiver.. See Fig. 1—the form used in 1903. Now, when one electrode was connected to the upright antenna and the other to the earth, I was able to clearly hear in the telephone receiver the signals from a distant wireless telegraph transmitter. The resistance of this new "flame detector" was decreased when the flame was enriched by a salt. Next the incandescent gases of an electric arc were considered; and likewise the action in the more attenuated gases of an ordinary lamp bulb, surrounding an incandescent filament or filaments.

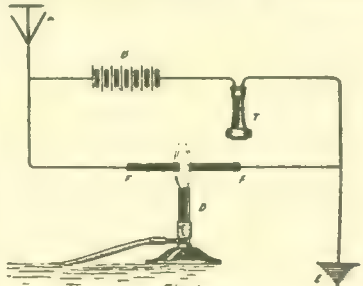


Fig. 1

"I Next Explored a Bunsen Burner Flame, Using Two Platinum Electrodes Held Close Together, Connected with an Outside Circuit."

But during these early years I was afforded little time to concentrate on this laboratory problem, and it was not until 1905 that I had opportunity and facilities for putting to actual proof my conviction that the same detector action which had been found in the neighborhood of an incandescent platinum wire, or carbon filament, in a gas flame existed also in the more attenuated gas surrounding the filament of an incandescent lamp. In one case the burning gases heated the electrodes; in the other the electrodes heated the remanent gases. But in both it was *first* the electrons from the hot electrodes, and *second* ionization of the gases which these electrons produced, which established an electrically conducting state, extraordinarily sensitive to any sudden change in electrical potential produced on the electrodes from some outside source.

Considering therefore this actual genesis of the audion it will be seen that it was never, strictly speaking, a *rectifying* device. True, both electrodes were seldom alike and a "polarization" was always had from the outside battery, but any rectification of the alternating currents impressed on the detector was merely incidental and played no vital part in the action of the audion. From the beginning I was obsessed with the idea of finding a *relay* detector in which local electric energy should be controlled by the incoming waves—and not a mere manifestation of the electrical energy of the waves itself. Hence it was that the external battery as a source of local energy was always employed when the incandescent filament was utilized as source of the electric carriers through the gas. The battery for lighting the filament Q styled the "A" battery and, as distinguished from this, the other battery was named the "B" battery This nomenclature has been retained, and is today commonly accepted, even by the many who for various reasons refuse to recognize the name "audion."

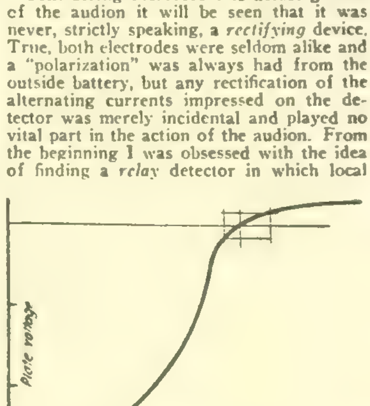


Fig 4

"This Curve Shows Why, Were Even Both Anode and Cathode Hot, the Reception of Waves Would Produce a Change in the Normal Phone Current."

At the period now under consideration, 1903-05, I was familiar with the Edison effect and with many of the investigations thereof carried on by scientists, Professor Fleming among others. In 1904 I had outlined a plan of using a gas heated by an incandescent carbon filament in a partially exhausted gas vessel as a wireless detector, in place of the open flame. But here the rectification effect between hot filament and a cold electrode was not considered. Two filaments, heated from separate batteries, would give the desired detector effect equally well What I had already found in the flame detector and now sought in a more stable and practical form, was a constant passage of electric carriers in a medium of extraordinary sensitiveness, or tenuity, which carriers could be in any conceivable manner affected to a marked degree by exceedingly weak electrical impulses, delivered to the medium, indirectly or thru the hot electrodes. Fig. 2.

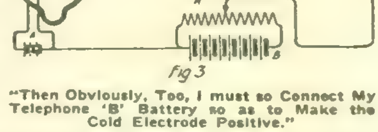


Fig 3

"Then Obviously, Too, I must so Connect My Telephone 'B' Battery so as to Make the Cold Electrode Positive."

The ordinary small incandescent lamp of that epoch supplied admirably the conditions I required merely by the introduction of a second electrode. That added electrode could be either hot or cold. Obviously, therefore, use it cold, avoiding thus the unnecessary battery. Then obviously, too, I must so connect my telephone "B" battery as to make this cold electrode positive, for otherwise no local current could flow through the gaseous space in the lamp between the unlike electrodes. Fig. 3.

The high frequency impulses to be detected were, as in the earlier flame type, originally applied directly to these same two electrodes. That these alternating electric currents were thereby rectified was merely incidental. A glance at the plate-current, plate-voltage curve (Fig. 4) shows why, even were both anode and cathode hot, the receipt of a train of high-frequency current waves would produce a resultant change in the normal telephone current and result in a signal. This typical curve, taken from a "gasey" lamp, such as I first employed, is curvilinear over two portions. If now the "B" battery potential was so adjusted that the detector was operating on either knee of this curve the increase to this locally applied voltage, resulting from the positive halves of the wave-train, would produce a greater

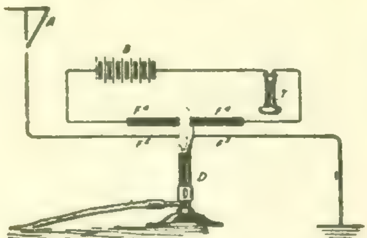


Fig. 5

This Shows the Original Idea of Keeping the High-Frequency Current Path Distinct from the Local Telephone Current.

(or less) increase in the local current flowing across the gap than would the negative halves of the wave-train produce a decrease (or increase, as the case might be).

In other words, the responsive action of this two-electrode audion was due to the asymmetry of its characteristic curve rather than to its rectifying property. This latter property could be made to aid, to increase the intensity of the signal produced originally and mainly by the so-called "trigger" or genuine *relay* action of the device, which was always *controlling* the local energy by means of a much smaller income energy.

In other words, then, the two-electrode audion, with "A" and "B" batteries, was not primarily a "valve." And I have always objected to this misapplication of the name *valve* to the audion; a name which our British friends have from the first persisted, with a stubbornness worthy of a better cause, in misapplying!

Long before the two-electrode relay audion of 1905 had a chance to prove its worth in commercial wireless service I had found that the influence of the high-frequency impulses could be imprest to better advantage on the conducting medium from a third electrode. In its first inception the third electrode also dates back to the flame detector of 1903. Fig. 5, taken from the earliest patent of the audion group, shows the original idea of keeping the high-frequency current path distinct from that of the local telephone current. Consequently when in 1906, having secured the maximum efficiency from the two-electrode vacuum type, I cast about for further means of improvement, it was but natural to revert to this plan of separating the two circuits. The new electrode connected to the high-frequency secondary circuit was at first applied to the outside of the cylindrical lamp vessel; the other terminal of the secondary circuit was led to one terminal of the lamp filament. Fig. 6, of a 1906 patent, shows this progenitor of the third electrode. This simple arrangement proving a step in advance, I concluded that if this auxiliary electrode were placed within the lamp the weak charges thereto applied would be yet more effective in controlling the electron-ionic current passing between the filament and plate.

Fig. 7, taken from a patent filed two months after the preceding one, illustrates the next arrangement tried. Here I used two plates, one either side of the filament—one in the telephone circuit, the other in the high-frequency circuit associated with the antenna. It will be noted also that here for the first time was shown the third, or "C" battery, in the input circuit, so much employed of late, notably when the audion is used as amplifier of telephonic currents. This two-plate device proved another decided step forward, and I realized then that if this third electrode were placed directly in the path of the carriers between the filament and plate anode I would obtain the maximum effect of the incoming impulses upon the local current flow. But obviously another electrode thus placed direcly in the stream must not be a plate—it must be perforated to permit the carriers to reach the anode. A wire bent back and forth in form of a grid should answer admirably. Fig. 8, taken from the patent filed in January, 1907, the so-called "Grid Audion" patent, illustrates the preferred form which the idea promptly assumed.

In surveying the wide field of electric communication today one cannot look back at that little figure, of the first grid electrode, without a sense of wonder at the enormous changes which it has wrought. It has made possible *commercial* trans-oceanic radio telegraphy. It has realized transcontinental telephony: it has made reception of wireless signals half-way around the globe an everyday occurrence. The uncanny

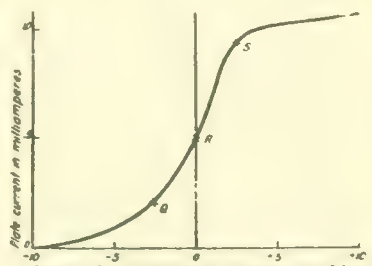


Fig. 9

Curve Showing the Expression of the Current Going from Filament to Plate.

accuracy of millions of shells from the Allies' guns, the clock-like precision of advancing barrages, would have been impossible save for the effectiveness of their trench and airplane radio service, in which the grid audio was the essential heart. Today this little grid controls and modulates an ever-increasing kilowattage of radio telephone energy, which as early as 1915 conveyed the spoken voice from Arlington to Honolulu, and more recently from New Brunswick to the transport *George Washington*, in the harbor of Brest. It has already placed twenty simultaneous telephone messages upon a single pair of wires. A few ounces of grid wire make possible the saving of hundreds of tons of copper in long-distance telephone conductors. It has given to the physicist a tool for the exploration of unprobed fields of research; and to the electrical engineer a generator, without moving parts, of alternating currents of any desired frequency, from one to ten million period per second—a machine absolutely constant and reliable in its silent work.

Let us consider briefly the explanation of all this radical advance, the theory of the invisible mechanism whereby this astonishing control of powerful energies by minute impulses is effected. Lacking a very concrete conception of just what electrons are and just how electric charges residing on a grid can so effectively dam back the flood of electrons expelled at enormous velocities from a hot cathode at the urge of high potentials—our minds must be content with pictures of characteristic curves and mathematical formulæ, at best but crudely interpretive.

The fundamental operating characteristic

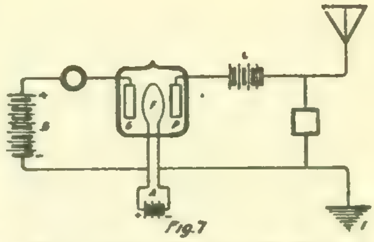


Fig. 7

In This Instance We Have the Next Arrangement Tried Following That of Fig. 6.

of the audion is that expressing the current flowing from filament to plate in terms of the potentials supplied to the grid. Fig. 9 expresses this relation graphically. Here we see that a moderate negative potential (10 volts) applied to the grid completely cuts off the current between filament and plate. As this negative grid charge is reduced to *O* the plate current rapidly increases. As the grid potential becomes positive this plate current continues to increase up to a point *S*, after which it rapidly approaches a saturation value, above which the plate current will not rise, regardless of how high is the positive potential applied to the grid. This curve was taken with a given fixt potential difference applied between filament and plate, and for a given filament temperature. This sample characteristic was taken from a "hard" audion, from which the gas has been sufficiently well exhausted to show no irregularity in its curve, due to ionization. It will be observed that over the straight-line portion of this curve, between points *Q* and *S*, when the grid potential varies a small but equal amount on right and left of zero, the amplitude of variation in the plate current is directly dependent on the variation of the applied grid potential. In other words, there will be over this range no distortion between the wave form of the incoming alternating potential imprest on the grid and that of the current fluctuations produced in the plate, or output, circuit. Obviously, therefore, the straight-line portion of the audion characteristic is the one to utilize in an audion amplifier, or repeater, whether for amplifying radio or voice-frequency currents. Consequently we find telephone engineers going to extreme lengths to so design their audions and circuits, and to so regulate the potentials applied to the grid, as to operate entirely within this straight-line characteristic. The result is a perfect reproduction of voice currents, but magnified to any extent desired by the use of two or more such amplifiers connected in cascade—from ten to twenty thousand times or more.

But when the audion is used as a simple detector of dampt radio signals, where it is desired to obtain the maximum possible integrated effect from a train of incoming high-frequency waves upon the direct current in the plate circuit, it is desirable to operate at the lower, or upper, knee of this characteristic curve, for the reason already explained. Here we have taken advantage of the asymmetry of the curve, so that the sum of the decreases in the plate current as

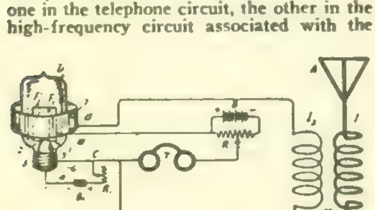


Fig. 6

This Illustration, Taken from a 1906 Patent, Shows the Progenitor of the Third Electrode.

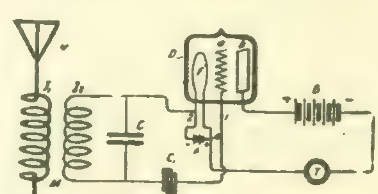


Fig. 8

This Arrangement, Taken from a Patent File of January, 1907, Illustrates the Preferred Form of Element Arrangement.

the grid potential decrease, greatly outvalues the sum of the increases in the plate current, when the grid potentials increase. This results in an integrated decrease in the current through the telephone receiver, which may represent much greater energy than that of the incoming wave-train.[1] It is thus that the audion can operate as a true *relay* device, possessing a sensitiveness far greater than that of the most perfect crystal rectifier, or of any valve. Consideration of the advantage of thus working on the asymmetric portion of the audion curve would lead us to expect an increase in sensitiveness as a detector of spark signals if this asymmetry be further emphasized by the introduction of a small amount of gas into the bulb, thus producing a very appreciable amount of ionization. Such has long been known to be a fact—no high vacuum audion today equals, as a radio detector, the "soft" bulbs which were in very general use a few years ago. The presence of such an amount of gas is usually evidenced by a blue haze seen around the anode when high potentials (say from 60 to 100 volts) are applied across plate and filament. Ionization phenomena always introduce certain irregularities in the operation of the audion and kinks or cusps in its characteristic curves—even where the gas pressure does not greatly exceed one-ten-thousandth of a millimeter of mercury.

Our knowledge of electrons is of comparatively recent date. In 1899 J. J. Thompson showed that negative electricity is given off from a heated carbon filament in the form of electrons having a mass of 1/1800 that of a hydrogen atom. These electrons may be considered as atoms of electricity. Richardson, in 1903, first applied the electron theory of metallic conduction to emission from heated conductors. He assumed that electrons are ordinarily held bound within the metal by an electric force at the surface, by a tension similar to the surface tension of liquids. But if the velocity of an electron be made sufficiently high, as by applied heat, it is able to overcome this surface force and escape. The number of electrons, therefore, which attain the necessary critical velocity to escape will increase very rapidly with the temperature. The laws are similar to those governing the increase in vapor tension of a liquid with increasing temperature. Richardson thus concluded that the electronic emission from an incandescent metal should increase according to a similar equation:

$$i = a\sqrt{T}\,e^{-\frac{k}{T}}$$

where i is the current per square centimetre at temperature T, and k is a constant dependent on the latent heat of evaporation of the electrons. But actual investigations of the Richardson law, notably by Dr. Langmuir, showed that as the heat of a cathode filament was increased the thermionic current increased first in accord with Richardson's equation, but that beyond a certain point further increase in temperature produced no further increase in thermionic current.

A family of saturation curves, each one corresponding to a certain applied fixt potential between cathode and anode, results, as shown in Fig. 10, where the first parts of the several curves combine to form a single curve following Richardson's law. These curves [2] show that the thermionic current does not continue to increase as expected, because the space surrounding the hot filament is capable of carrying only a certain current for a given potential difference. The explanation offered is that the electrons surrounding the filament soon set up a "space charge" which repels new electrons escaping from the filament, causing some to return to the filament.

From a study of the curve family of Fig. 10, Langmuir has evolved a formula introducing the factor of plate potential, in the case of a filament coaxial with a cylindrical anode. Here the current in amperes

$$i = 14.65 \times 10^{-6} \cdot \frac{V^{\frac{3}{2}}}{r}$$

where r is the radius of the cylinder in centimetres. But extremely minute amounts of gas vitiate the correctness of this formula by neutralizing more or less the space charge.

Therefore for a power oscillator a certain definite amount of gas in the tube may prove a distinct advantage. The filament, if of tungsten, has a tending to absorb gas, so that if a small amount only is left in the tube on exhaustion the audion shows a tendency to grow "harder" with use. A perfect vacuum is never attained; spectrum analysis shows traces of residual gases always present, even in the "hardest" of tubes.

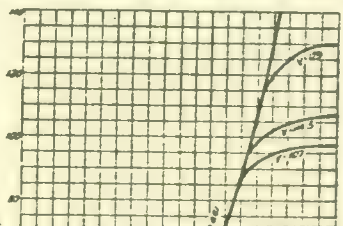


Fig 10

In This Case We Have a Family of Saturation Curves Each One Corresponding to a Certain Applied Fixt Potential Between Cathode and Anode.

If powerful bombardment of anode plates is long continued, gases will be thereby driven out from the metal and the tube rapidly become too soft to be of use—unless the gases have first been thoroly exhausted from all metal parts within the oscillion, by methods well known to the X-ray tube art. Moreover, too much positive ionization tends to disintegrate the cathode filament. With negligible ionization there appears to be no disintegration of the filament by the electronic discharge, and its life is as great as tho no electronic current flowed.

We have just seen, then, how the space charge surrounding a hot cathode can, in the absence of sufficient ionization, produce a saturated condition of the plate current. This current, or number of electrons emitted, is fixt by the cathode temperature for a given applied voltage, while the velocity of the electrons is dependent on this applied voltage. These electrons, escaping from the cathode and producing the choking space charge, can equally well charge up a third electrode located in this space to a considerable negative potential with respect to the cathode. It will be seen, therefore, how readily one can expect to control the plate current by means of relatively small potentials, positive or negative, applied to this control electrode, the grid. But the presence of the grid between cathode and anode so complicates the electric field distribution that a theoretical analysis of the relation between the plate current and the plate voltage and the grid voltage (with respect to the filament) is too complicated to be of any practical use. Empirical formula for predetermining the characteristics of various types of audion have been evolved. These, unlike the greater mass of mathematical writings already flooding this new art, are actually proving of some real help to the tube engineer.

In a highly exhausted bulb the so-called "space charge" ordinarily acts to very quickly limit the thermionic current flowing from the hot cathode to the cold anode, but the present of positive ions partly neutralizes this space charge. Now if a small positive charge be applied to the grid the velocity of the electrons passing thru it is increased, and consequently they produce more ions by bombardment. Moreover, the number of electrons passing the grid is increased, which in turn again increases the ionization. If too much gas is present, permitting too large a plate current to flow, the relaying action of the audion disappears, because the grid charges are then unable to control the large ionic currents. This condition is usually evidenced by the visible blue glow. In the region between these two limits the audion may possess an extraordinary sensitiveness, as is usual with any condition of instability.

In the early days when audions were exhausted, like the ordinary incandescent lamp, by oil pumps merely, it was ordinarily impracticable to exhaust to such high vacua as to permit the use of more than 40 to 80 volts of B potential, without producing this excessive ionization. However, in 1912, when I first began to construct larger bulbs for large amplification of telephonic currents, it became apparent that the higher voltage necessary for producing the loud amplifications desired required higher and higher potentials, which obviously necessitated higher vacua, and better methods of exhaustion. It was then for the first time that I caused audion bulbs to be exhausted by X-ray tube methods, enabling me to apply several hundred volts of plate potential. So the perfecting of means for exhausting the bulb kept pace with the growing requirements for larger power to be handled. There was at no time in the evolution of the audion, from the original incandescent lamp vacuum to those high exhausts now necessary in the largest "power-tube," or oscillion, any definite demarkation in the degree of vacuum needed or obtained. The lampmakers' and glassblowers' skill kept pace with the radio engineers' requirements of larger bulbs and greater amounts of energy handled.

In the earlier types of audion detector a stopping condenser in the grid lead was usually, but not always, employed. There were then sufficient ions in the bulb to ordinarily prevent the gradual accumulation on the thus insulated grid of a large negative charge, which would very rapidly completely cut off the plate-filament current. However, when heavy static discharges struck the receiving antenna it was frequently observed that the audion would be "paralyzed" for several seconds thereafter. We early learned how to discharge this residual negative accumulation on the grid, at first merely by putting the wetted fingers across the grid and filament terminals. This primitive "grid leak" was soon made in permanent form—for example, a wet string, and later a high-resistance graphite pencil mark. As the degree of vacuum of the bulb was increased the necessity for this grid leak became more urgent, and since 1913 it has been generally applied to all high vacuum tubes, when stopping condensers are used; whether the bulb be a detector, amplifier, or generator of alternating currents.

Part 1 of a paper read before the Section of Physics and Chemistry and the Philadelphia Section, American Institute of Electrical Engineers, January 15, 1920.

Part 2 of this interesting historical paper will be publisht in the November number of RADIO NEWS.

[1] Where a "C" battery is employed for keeping the grid always negative, the audion is operated on the lower knee of its characteristic curve.

[2] Due to Dr. Langmuir.

The Audion—Its Action and Some Recent Applications

By LEE De FOREST, Ph. D., Sc. D.

Part 2

A historical paper of unusual interest to the Radio 'raternity

It was in the summer of 1912, when at work on the problem of audion amplifiers in cascade arrangements for telephone repeaters, that I fir discovered that if the input, or grid, circuit was inductively coupled with the output, or plate inductance, the audion became a generator of continuous alternating currents, originally made evident by a shirll tone in the telephone receiver. A typical regenerative circuit is illustrated in Fig. 11. The explanation of the operation is simple. An initial impulse the plate circuit, however produced. induces a similar one ir the grid circuit, which, if of proper polarity, will impress on the grid a sudden change in potential which may in its turn produce an impulse in the plate current in the opposite direction to the original disturbance. This reaction then becomes self-sustaining, provided the resistance and hysteresis losses in the two circuits are not too great; and the amplitude of the oscillating current thus set up goes on increasing, taking energy supply from the B battery, until the losses . the circuits equal the increment of energy drawn from the battery. Whereafter a alternating current of perfectly constant amplitude and wave form is maintained. The fr quency of this alternating current depends on the constants of the circuit, the inductance and capacity in the input or output circuits. But under certain conditions it depends to some extent also on the recistance in the grid leak, if this be used, and sometimes, but not usually, on the temperature of the filament and the B voltage.

Fig. 16. Typical Oscillion Transmitter Which Utilizes Two Half Kilowatt Vacuum Tubes.

A few months after this type of circuit was first used for the production of alternating currents of audible frequency I first demonstrated the fact that weak *high-frequency* currents could equally well be generated, simply by substituting radio-frequency coils for the original iron-cored coils, and small variable air condensers for the large telephone condensers of the original experiment. And quite naturally, also, since I was at the time engaged chiefly in work on undampt wave radio transmission, this generation of radio frequency waves was first demonstrated in receiving heterodyne, or more exactly autodyne, signals. The circuit used at this early date, April, 1913, which was almost identical with that in Fig. 11—Fig. 12, shows the usual antenna receiving circuit, the usual secondary circuit connected across the grid and filament of the audion, but with another coil similar to the secondary in series with the telephone receiver, which in this case was abridged by a small condenser.

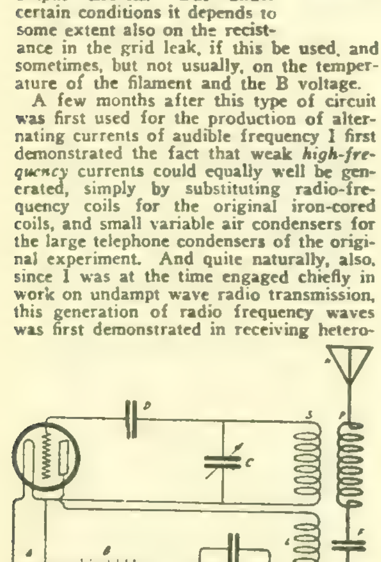


Fig 12

An Early Autodyne Circuit Used by Dr. DeForest.

AN ACCIDENTAL DISCOVERY

In the fall of that year my assistant, Mr. Longwood, and I discovered, largely by accident, that if the secondary receiving circuit be connected across the grid and plate, instead of as customary between the grid and filament of an audion, the circuit became a persistent oscillator, very simple and effective as a receiver of undampt wave signals. On account of the great sensitiveness of this combination the name "ultraudion" was applied to it. Countless modifications and adaptations of these two general types of oscillating audion circuits have been developt by radio men here and abroad. For their simplicity, the ease with which all the advantages of the beautiful heterodyne principle of Prof. Fessenden and Vreeland can be realized, the clarity of note and range of pitch which the receiving operator can instantly command—coupled with a degree of sensitiveness of a different order from that of any other type of detector—these advantages very quickly relegated to the scrap-heap the ticker and tone-wheel; and at once placed the transmission by undampt waves upon an altogether different level from that of the older spark method.

But the audion in an oscillating or an almost oscillating, or unstable, condition is also of great utility in detecting dampt wave signals, or even radio telephone currents. If the two circuits, input and output, are so separated as to interact less energetically the oscillations become weaker and finally cease to be generated. When in this condition a very feeble impulse, if properly attuned, can set the system into vibration. The resulting response develops an energy almost unrelated to the cause. Enormous magnifications are thus possible with a single audion, and spark signals have thus been received over the greatest span which it will ever be possible to reach on this earth—half way around the globe.

In receiving undampt wave signals, when the local oscillating receiver circuit is slightl out of tune with the incoming waves, the received currents on reaching the grid are amplified, first by the ordinary processes of the audion, and then combine with the local oscillations to produce "beat" notes, of audio-frequency which beat note currents are themselves amplified by the audion, before delivery to the telephone receiver. So sensitive is the pitch of this beat note to the slightest change of capacity or inductance in the circuit (when very high frequencies are employed) that in properly designed circuits a change of capacity of one-thousandth part of the electrostatic unit can be detected. A change of capacity which is caused by substituting coal gas for air in a condenser can thus be easily measured. Similarly can be demonstrated slight changes in resistance with temperature of conductors, the conductivity of flames, the permeability of liquids, etc. Very recently Prof. Blondel has utilized the audion in a balanced bridge method for measuring excessively slight differences in static potentials

The uniform generation of electrical oscillations in a circuit by means of an audion

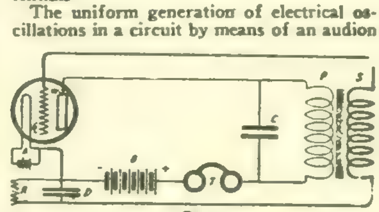


Fig 11

Another Fundamental "Feed Back" Circuit Employed in Developing the Audion.

is one of the most striking and fascinating of its applications. If these are of radio-frequency there is no sensible manifestation

of their presence, but if of audio-frequency the telephone receiver or "loud speaker" reproducer may be made to give forth sounds from the highest pitch or volume to the softest and most soothing tones. Such wide range and variety of tone can be produced from suitably designed singing circuits that a few years ago I prophesied that

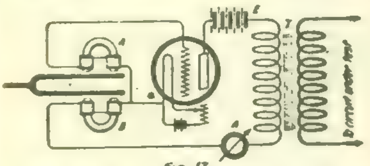


Fig. 13

In This Case a Tuning Fork is Driven by Electro-Magnets.

at some future time a musical instrument, involving audions instead of strings or pipes, and batteries in place of air, would be created by the musicians' skill.

DRIVING A TUNING FORK

But lower frequencies, even to one oscillation per second, can be obtained from the audion. Pulsations suitable for submarine cable signalling, or for chronograph and time-pendulum work, can be had of remarkable constancy and reliability, free from all difficulties of speed regulation of motors, or of any moving parts. Or a combination of mechanical time-factors, and the electrical properties of the audion can be advantageously employed. For example, a tuning fork may be driven by electro-magnets, one connected in the grid circuit, the other in a plate circuit, as shown in Fig. 13.

The movement of the grid prong here induces an e. m. f. on the grid, which in turn controls the plate current thru the other coil acting upon the other prong of the fork, thus sustaining its motion. If the two coils here shown are also closely coupled inductive reaction, or regeneration, is added to the mechanical, and very powerful vibrations may be thus set up. Various modifications of this principle will suggest themselves to physicists, who desire sparkless generation of low frequencies of great constancy. Tuned relays, highly selective to definite frequencies, and where it is desirable to reduce the damping to zero or nearly zero, can thus be constructed. The above arrangement is due to Messrs. Eccles and Jordan.

A modification of this method of linking the audion with mechanical motion is the magnetic pendulum, actuated by the plate currents through electro-magnets and inducing in another coil properly tuned impulses which, if conveyed to the grid, control thru almost senusoidal currents the successive pulls upon the pendulum (Fig. 14). When a second system identical with the first, but located at right angles thereto, is employed, the pendulum will be set into conical vibration, circular or elliptical as desired, and a revolving electric field will be produced, which can also be made to drive an armature or magnetized wheel at a certain definite speed.

There seems to be, in fact, no limit to the number of applications to which this three-electrode vacuum tube can be applied as a tool in the hands of the experimental physicist. Of especial value is the fact that it renders easily available devices having ***negative electrical resistance***, as in the four-electrode device of Dr. Hull (styled the "dynatron")—or its equivalent in some mechanical form. For one fundamental property of the audion is that an electrical influence in one circuit may, thru the grid, be made to produce effects in another circuit without appreciable reaction. For the energy absorbed by the control electrode may be considered negligible—frequently less than that required in moving a galvanometer needle.

THE MICROSCOPE OF RADIO

Then, and probably the most promising field of all, the arrangement of audions in cascade as amplifiers, of pulsating currents of any form or frequency—opens to the ear what the microscope has given to the eye—new regions of research in numerous and diversified fields from physiology, for heart beats and breath sounds — to chemistry, where some even predict that we shall some day hear "the collision of individual atons with one another." During the war British army engineers used as many as nineteen audion bulbs in cascade circuit, amplifying preferably the radio instead of the audion frequency currents. With such a series it is possible to detect with certainty alternating currents of one-ten-thousandth-millionth of a volt on the input grid—involving magnifications of the order of twenty thousand times. It is an everyday occurrence now to receive radio messages from Norway or Honolulu, on a closed-loop antenna one metre in diameter, using three or more audion amplifiers in cascade between this antenna and the detector, and sometimes a similar multi-stage amplifier for audio frequencies, between the detector and the telephone receiver.

Principles which, tho long understood were impossible of application to radio signalling, have been made realizable by the audion amplifier, and the scope and value of the new art immeasurably increased thereby. For example, the use of underground receiving antenna, the direction-finder, or radio-compass loop, the elimination of static interference by either of the above, or other methods—all such were compelled to await for their successful application the introduction of the grid electrode. Starting with the small bulb used in 1912-13 as a telephone amplifier and generator of minute electric oscillations for heterodyning purposes, I began the construction of larger sizes to be used in undampt wave transmission. At first spherical bulbs, three or four inches in diameter, and taking 50 watts of plate input energy, were considered large. Such rapid progress was made in improvement of design and construction of these so-called "power tubes," notably by the engineers of the Western Electric Co., that by autumn of 1915 a bank of several hundred tubes, their input and output electrodes connected in parallel, were installed at the Arlington wireless station. By a pyramidal circuit arrangement, whereby one oscillion tube con-

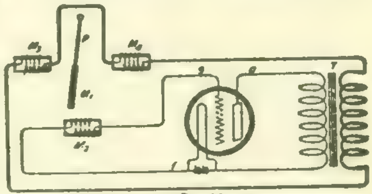


Fig 14

Linking the Audion With Mechanical Motion By Means of a Magnetic Pendulum.

trolled a group in parallel, these in turn controlling larger groups of oscillion tubes, some twelve kilowatts of undampt wave energy was delivered to the great antenna, all perfectly controlled or modulated by an ordinary telephone microphone. By this arrangement the voice was transmitted that year as far as Honolulu and Paris, thus fulfilling predictions made in 1909 to a very skeptical world.

THE ALEXANDERSON MAGNETIC AMPLIFIER

In these Arlington tests the entire system was one of three-electrode tubes—for power generator, for current modulation thereof at the transmitter, and for detector and amplifier at the receiver. More recently Alexanderson, using his powerful high frequency alternator at New Brunswick, has controlled 80 kilowatts of antenna energy by means of his magnetic amplifier. This ingenious development of a Fessenden device was in turn controlled by a bank of large audion amplifier tubes, nicknamed "pliotrons," whereby the original microphone currents were sufficiently amplified to control the saturation currents necessary for the magnetic controlling device.

There are today grave differences of opinion among radio engineers as to what type of high-power radio transmitter will prove the key to the future—the high-frequency alternator, the Poulsen arc, or the oscillion. In my own opinion, the long-distance transmission art will shortly depart from true radiation methods; and the a. c. generator, of comparatively *low* frequency, will be widely used for such subterranean, or submarine transmission, leaving for ship commiuncation only the survival of radio transmission, as it is known today. Such being the case, we will then have little use for *radio* transmitters of more than 20 to 50 kilowatts. For such transmitters I foresee the early use of a few large oscillion tubes, of, say, kw. capacity each. Already we are making tubes capable of handling one and two kilowatts, using tungsten filaments and grids, and large anode plates of tungsten or molybdenum. The efficiency with which several such tubes can operate in parallel, the case with which an amplified voice current, acting upon their grids in parallel, can control their combined output, make such a sys-

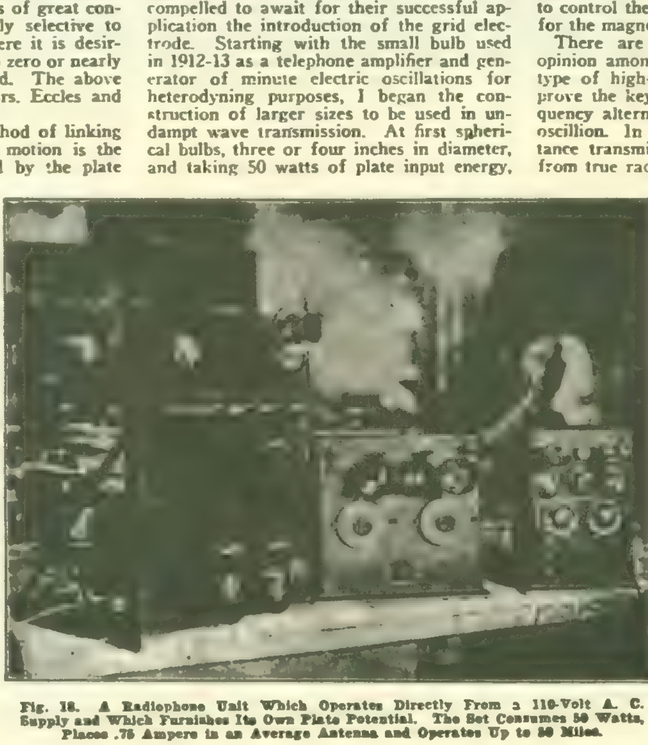


Fig. 18. A Radiophone Unit Which Operates Directly From a 110-Volt A. C. Supply and Which Furnishes Its Own Plate Potential. The Set Consumes 50 Watts, Places .75 Ampere in an Average Antenna and Operates Up to 50 Miles.

tem almost ideal as a radio telephone transmitter. A typical oscillion transmitter utilizing two half-kilowatt tubes is illustrated in Fig. 15. The schematic circuit diagram for such a transmitter is shown in Fig. 16.

LARGE TUBE CONSTRUCTION

In the construction of these large tubes a thousand details must be scrupulously observed—in addition to the calculated physical dimensions of the elements, the choice of materials, the method of seal, the preliminary treatment of the metals, their welding, the screening of the glass from bombardment, the various steps in the process of exhaustion—on careful observance of all these alone depends success in the manufacture of a high-power tube. A reasonably long life, of 500 to 1000 hours, is afforded by the tungsten filament, pure or alloyed with thorium; but this is by no means an ideal source of electrons. As such, tungsten, while preferable, is highly inefficient. By coating fine platinum ribbon with oxides of calcium, strontium, etc., or of the rare earths, similar to those in the Nernst glower, far higher emission efficiency is had, at lower temperatures, with resultant increase in l· But such oxide-coated filaments are fragile and very frequently damaged during exhaust. Moreover, many types of coating lose their power of electron emission after a time. This method seems at best an imperfect makeshift. What the audion art awaits is a ribbon filament of some new, well-conducting alloy, wire drawn or rolled of non-crystalline structure, emitting floods of electrons at a heat lower than visibility. Reward awaits the metallurgist who first produces such a filament. For to-day the audion is being produced in quantities which in pre-war days would have been considered fantastic exaggeration. During the last months of the war the world production of such bulbs had attained the incredible rate of 1,000,000 per annum. And now the demand in America alone, chiefly from radio amateurs and experimenters, is at the rate of 5,000 per month, and constantly growing. And most of these latter are used singly or in two-step amplifier arrangements. During the war, however, thousands of amplifier and transmitter instruments, each requiring 3 to 9 bulbs, were in use—in earth telegraphy, in submarine listening, in telegraphy by ultra-violet or infra-red rays, in gun-spotting, airplane detection, etc., in addition to those required for ordinary radio telegraphy and telephony.

The necessary conditions for an audion to function as a generator of alternating currents have been the subject of exhaustive study by many investigators, notably by Hazeltine, Ballantine, and Mills in this country; Vallauri and Eccles abroad. There are today countless circuit arrangements whereby the audion may be caused to generate such currents; but in all of the practically useful ones, where considerable power is required, the inductive linking of the grid and plate circuits, analogous to that first used in 1912, is in one form or another employed. One of the simplest forms of such circuit is shown in Fig. 17. If there is no time lag in the electronic stream behind the pulsations of grid voltage, as is the case in a highly exhausted tube (up to frequencies of ten million per second), then the

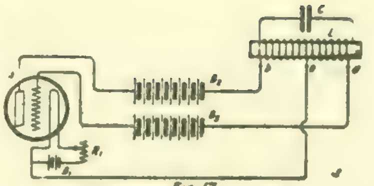


Fig. 17
Simple Form of Inductive Linking of the Grid and Plate Circuits.

above arrangement becomes an alternating current source whose frequency depends upon the natural frequency in the *LC* circuit. The period of this oscillation is very nearly $2\pi\sqrt{LC}$ if the resistance, *r*, of the external plate circuit is small, the resistance, or reactance, *p*, of the plate-filament gap is great, and provided the mutual induction, *m*, between the inductances in the grid-filament and plate-filament circuits is just sufficient to maintain the oscillations.

If, then, $m \geqq \frac{1}{k}\left(\frac{L}{p} + r.C\right)$

this oscillating condition is realized; and *K* in this formula can be defined as the "amplification factor."

THE USE OF A.C. FOR PLATE SUPPLY

One of the latest developments in the oscillion transmitter is the application of alternating current for the plate voltage supply. Sixty-cycle current is taken from a lamp socket, stept up to 500 or 10,000 volts (according to the size of the transmitter)—the two halves of the cycle rectified thru two-electrode vacuum valves, this rectified current stored in a suitable condenser, smoothed out by an appropriate "filter" circuit, and finally delivered as high-voltage direct current to the plate-filament circuit of three-electrode oscillator tubes. The filaments of both rectifiers and oscillators are lighted from the low-voltage windings on the one transformer. Such an arrangement does away with the motor generator converter, and even with 60-cycle supply gives surprisingly clear voice transmission. A small set of this type employing two rectifier and four small oscillating audions in multiple is shown in Fig. 18. With this small unit, consuming 50 watts and putting three-quarters of an ampere in an average antenna, one has recently telephoned fifty miles.

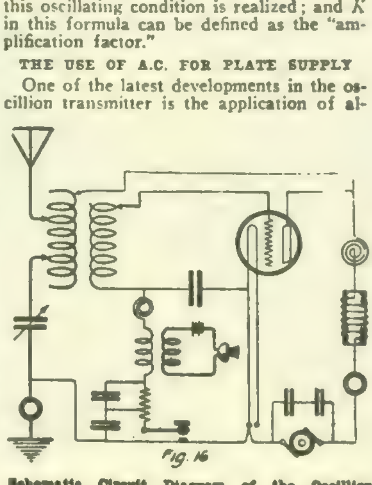


Fig. 16
Schematic Circuit Diagram of the Oscillion Transmitter Panel Shown in Fig. 15.

Vivid Illustration of the Completeness With Which the American Telegraph and Telephone Co. Have Applied the Audion Repeater to the Commercial Long-Distance Telephone Service of the United States.

The developments by the engineering staff of the Western Electric Company of the audion amplifier as a telephone repeater, since my first demonstration to them of its possibilities in that field, are beyond all praise. The zeal and rare understanding of the elements of the problem with which this staff of trained men develop the amplifier and applied it to the long-sought transcontinental telephone line stand unique in the annals of brilliant achievement in electrical engineering.

The time was ripe. Had the audion amplifier been presented at a much earlier date it is unlikely it would have then met the warm welcome which twenty years of futile search for the telephone repeater had earned for it. It was the irony of inventive fate that this revolutionary telephone device was to come, not from those whose efforts had for years spun in the old rut of the receiver-microphone "siameesed" together, but from an art younger than telephony, from a device conceived for a quite different application—a wireless telegraph detector.

"From small beginnings the transcontinental line has been evolved. One element after another came. First the telephone receiver of Bell; then the Berliner—Edison microphone; then adequate line construction; the Pupin coil to prevent voice distortion—and finally the one missing link, the Audion Amplifier. Try to imagine one of the electronic carriers of the voice currents in this amplifier, and contrast it with a carbon granule of a microphone transmitter of the early telephone relays. Compare a soap bubble with a load of coal, and you will have some relative idea of the distinction between the delicacy and elegance of tion produced by twenty miles of standard the audion and that of the old microphonic relay." A more revolutionary step was never taken in the history of electrical engineering.

A repeater suitable for our present wire cable. This actually means that the repeater must be capable of delivering 256 times as much energy as it receives; that is, possess a telephone efficiency of some 26,000 per cent, and this without appreciable distortion of the most intricate of voice current waves, involving all frequencies from 100 to 3,000 per second. Any repeater or amplifier which

(Continued on page 333)

The Audion—Its Action and Some Applications

produces distortion of the speech currents is to that extent unfitted for use in tandem operation, because the distortion is cumulative in the successive repeaters; and mechanical amplifiers generally, and even the best of that type, produce distortion.

A large amount of unnecessary secretiveness or mystery was for some time thrown around the type of telephone repeater which made possible transcontinental telephony.

A well-known telephone engineer has recently stated that the audion amplifiers used by the American Telephone and Telegraph Company are practically distortionless, and are commercially used in tandem operation in regular installations, and were so used in the first transcontinental line, which would have been impossible without the use of the tandem arrangement. By actual trial over cable circuits approximately one thousand miles in length it has been found that as many as thirty of these audion amplifiers can be connected in tandem and produce excellent speech at the receiving end of the line. This engineer is authority for the statement that computation shows the attenuation of a cable circuit of this length to be so enormous that if all the power received on the earth from the sun could be applied in the form of telephone waves to one end of the line, without destruction of the apparatus, the energy received at the other end would be insufficient to produce audible speech without the use of amplifiers; whereas with thirty amplifiers used in tandem the relatively minute energy of ordinary telephone speech current at the transmitting end produced speech in the receiver at the opposite end which was both loud and clear, the amplification due to such a tandem arrangement of tubes being of the order of 10[illegible].

The audion which has been evolved to meet these requirements, most rigorous of all its numerous applications, differs in many details from the detector or the oscillating audion. The presence here of gas ionization sufficient to cause appreciable distortion cannot be tolerated, neither must the grid be permitted to be positive at any phase of the cycle of impresst voltage. A hundred other minor requirements, small, yet difficult of realization, have been patiently achieved by our telephone engineers, who now state that "the amount by which it (the audion amplifier) fails to meet all the requirements for a perfect repeater is so small as to be negligible except under the most rigorous conditions."

The illustration (Fig. 19) conveys a more vivid idea than any description of the thoro completeness with which the American Telegraph and Telephone engineers have applied the audion repeater to the commercial long-distance telephone service. It illustrates a typical group of repeater racks, each rack carrying two complete repeaters. This view was taken at one of the main repeater stations on the Boston-Washington underground cable line, located at Princeton, N. J.

The third and final part of this article will appear in our December issue

The Audion—Its Action and Some Recent Applications

By LEE De FOREST, Ph. D., Sc. D.

Part 3

An historical paper of unusual interest to the Radio fraternity

POPULAR attention has been attracted to the success of the recently announced application to line wires of wireless methods of transmission, reception and tuning, whereby multiplex telegraphy and telephony have been made possible over wires already loaded down with their ordinary communication. The original ideas of such multiplex telephony date back to the early nineties, when John Stone, Hutin and Leblanc disclosed methods all involving the same principle, that several alternating currents of superaudio-frequency, each from a separate source, could be directed over the same wire or pair of wires, each be modulated or controlled by its own microphone, or Morse key, and at the receiving station each frequency taken off by its own properly tuned circuit, and there retransformed into its own original telephone or telegraph current. But none of these early investigators utilized at that time the all-necessary integrating detector which was alone capable of retransforming the modulated high-frequency wave-trains back into the original audio-frequency currents. Here again the wire telephone requirements had to await the advent of a radio-detector.

Fig. 20. A Typical Two-Stage Audion Amplifier.

WIRED WIRELESS

General (then Captain) George O. Squier in 1910 carried out certain experiments which are destined to become classic as the new art of wired-wireless attains the important commercial proportions to which it is unquestionably destined. He, for the first time, used a constant, reliable source of undampt electric currents of high frequency for the transmitter, and an audion detector between each tuned receiving circuit and its telephone receiver. By this combination multiplex telephony became at once a realized fact.

Fig. 22. A Western Electric Double-Grid, Double-Plate Vacuum Tube Used for Detection and Amplification.

But so long as a high-frequency alternator was required at each transmitter station the wired-wireless idea could not become commercialized. Its first cost, the size and weight of it with its motor, its delicacy of speed regulation, its limitation to relatively low frequencies, all made this impossible. So again an important development was compelled to await the advent of the oscillating audion.

Supplied from a common filament-lighting battery, a common "B" battery, or d. c. generator, any desired number of tiny alternating current generators, each driving its own easily tuned circuit, can now be assembled in a small central station. The grid of each oscillator is voice-controlled from its local telephone circuit, and as many high-frequency "carrier" wave-trains superimposed upon a single trunk line pair, as it may be feasible to use without interferences between the modulated frequencies of the several conversations.

At present carrier frequencies ranging from 5,000 to 25,000 have been used commercially over a single pair of telephone wires, between Baltimore and Pittsburgh. A zone of frequencies of 2,500 is allotted to each conversation, which permits of eight simultaneous telephone conversations over the line, in addition to the usual "physical circuit" conversations. The constant frequency generated by each individual oscillion lies in the middle of each allotted zone of wave-frequencies, but the modulation of this "carrier wave" by the voice currents results in a wide band of frequencies (analogous to a spectrum band) on each side of the particular carrier-wave frequency. This means that at the receiving station it is preferable to employ, instead of a circuit attuned to the single frequency of the carrier-wave, a "band-filter," or combination of several tuning elements (inductance and capacity). This band-filter, then, is equally receptive to any wave-frequency lying within the prescribed limits, say 1,250 cycles on each side of the carrier-frequency, but offers very high impedance to all frequencies above or below the limits of the band-frequencies. By eight such band-filter receiving circuits the eight conversations are segregated, each delivered to its own proper audion detector and sent out on its own local telephone line.

But it is by no means necessary to limit wired-wireless to the use of such low frequencies as we have been considering. Certain tests were recently carried out in Canada which proved conclusively that frequencies as high as 500,000 per second can be used over telephone lines, including several miles of cable, without harmful attenuation. This demonstration widens very greatly the range of frequencies available for wired-wireless, with hope for a corresponding increase in the number of conversations, or telegraph communications, which can be placed upon a single pair of wires, or group of pairs. Moreover, with such high frequencies (say from 100,000 to 300,000 per second) the necessity for complicated band-filter receiving circuits vanishes, with obvious attendant advantages.

THE FUTURE

Wired-wireless is the youngest of the large family of methods for electrical communication of intelligence. He is indeed a bold prophet who will today attempt to foretell the limits of its application. That the great saving in line costs, the vast multiplication of available channels of long-distance communication which it makes possible will

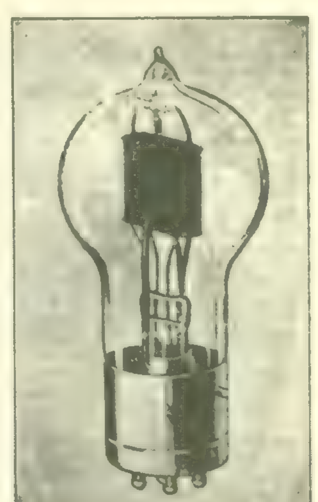


Fig. 21. A 50 Watt Vacuum Tube Used in Present Day Power Work as Met in Radio Communication.

Fig. [illegible] a 1 K.W. Oscillion Which Has Proved a Powerful Maker of Oscillations

work profound changes in our present methods of business, cannot be questioned. Thus again it seems evident that the audion is destined to play a leading rôle in the work of knitting more closely the people of this land, and of all lands.

We have briefly recounted some of the main achievements which the three-electrode audion, or triode, has to its credit. Let us now consider some of the possibilities of its future. From its invention until 1912 it attracted an almost negligible interest in the scientific world. A year after the audion was first brought to the attention of the engineers of the American Telegraph and Telephone Company that corporation acquired exclusive license under all the audion patents for wire telephone purposes. Thereupon the research men of that organization initiated an elaborate line of investigation of the device, which about that time began to interest other scientists in America and abroad. Prior to 1914 not a dozen articles on the audion had appeared in scientific publications. Today it is impossible to pick up a magazine devoted to physics or electric communication without finding one or several papers dealing with some of what Dr. Eccles styles "the protean properties of the ubiquitous three electrode tube."

Writing in the *Radio Review* Dr. Eccles (who is affiliated with the British Marconi Co.) says: "The most important single instrument in modern wireless practice is the three-electrode thermionic vacuum valve, for it enters into every main division of the subject—it plays a dominant part in the generation of oscillations, the detection of signals, and in the amplification of feeble voltages and currents. Its arrival and development have, besides, helped greatly toward the success of apparatus and methods that might otherwise have remained almost failures."

DR. ECCLES QUOTED

Dr. Eccles has outlined the present status and forecast of the future of the audion so clearly that I am constrained to quote further his words, as those of an unbiased observer: "During the war, hints reached the civilian that a revolution was taking place in wireless telegraphy, the principal agent in which was reported to be an instrument called a 'valve,' a 'lamp,' or a 'tube.' This instrument seemed to have arisen suddenly into a predominant position among all the apparatus of the wireless experimenter and operator, and appeared to be of use in every corner of his outfit. The complete name of the instrument is the three-electrode thermionic vacuum tube. It must be emphasized that it is the three-electrode valve, and not the valve with two electrodes, that has been responsible for the overthrowing of the old methods and apparatus. That it has been a veritable revolution can be seen by comparing the common practice in wireless telegraphy of 1914 with that of 1919. In 1914 practically all the most powerful transmitting stations in the world generated waves by sparks and signals which were received at nearly all stations by means of crystal or magnetic detectors. The spark method of generating waves involved the use of very large antennæ for spanning great distances; and at the receiving stations which wisht to listen to stations more than even 100 miles away very large aerial structures were customary. But if we look at the state of affairs today we find most of the high-power stations for long-distance transmission are 'continuous wave' stations; that is, they produce uniform uninterrupted waves instead of a series of short gushes made by sparks; while at the receiving end new modes of detecting these continuous waves appropriate to, and taking advantage of, their uniformity in character have been introduced. This is where the three-electrode tube, in various adaptations, enters the arena. Taken together, the improvements at both ends of the span have made possible the use of smaller antennæ at transmitting stations, and have almost removed the necessity for any antenna at all at receiving stations. For example, under reasonable weather conditions, it is quite easy to listen to the messages coming from stations on the other side of the Atlantic by using a receiving circuit of which the receptive element is a small coil of wire, three to four feet square. Thus, so far as receiving goes, it is possible to intercept all the great stations on one-half of the globe by means of apparatus contained wholly in one room, or even in a cupboard. In accomplishing this the magnifications in use amount to several hundred thousandfold. All this is the work of a thing which looks like an ordinary electric light bulb with a few extra pieces of metal in it—the three-electrode tube."

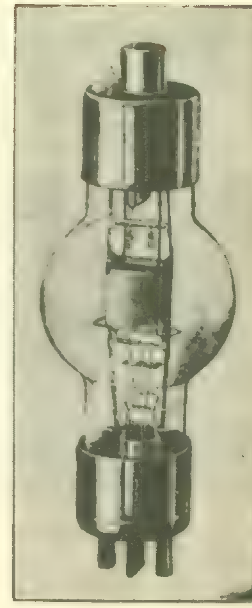


Fig. [illegible] a Smaller Power Tube of the ¼ K.W. Oscillion Type

Years ago what physicist did not look at the simple, self-contained, noiseless incandescent lamp, consider it as an ideal source of electro-magnetic waves of a wide spectrum—of heat, visible, and ultra-violet radiation, and wonder why it should not be made to generate also waves of any length? Today that incandescent lamp, with the addition of a metal plate and wire grid, has become such a generator. Undampt Hertzien radiations of a few centimeters wave-length can be generated by audions specially designed to give minimum capacity between the three electrodes and their lead-in wires. From these short waves, representing alternating current frequencies of some hundreds of millions, down to those of one or two per second, the electric-wave spectrum afforded by the oscillating audion is continuous. Consider this fact in connection with the almost infinite sensitivity of the device as a detector, and its unlimited power as a magnifier, or amplifier, and one realizes something of the value of the three-electrode vacuum tube to the physicist and the inventor. To the former, however, the keenest interest lies perhaps in the audion itself, because there is no known piece of electrical apparatus linked so directly with the most recent work on the structure of matter. A prominent British physicist has recently remarked: "It is probable that there is no other sphere where research work has had such a combination of immediate practical value and intense theoretical interest."

Many an early experiment in telegraph transmission or reception by wire or wireless, long since abandoned as too limited in range, can today be revived to the great benefit of man. Calculations have shown that with a littoral cable stretched for fifty miles on each side of the Atlantic, and carrying some forty amperes of 20-cycle alternating cur-

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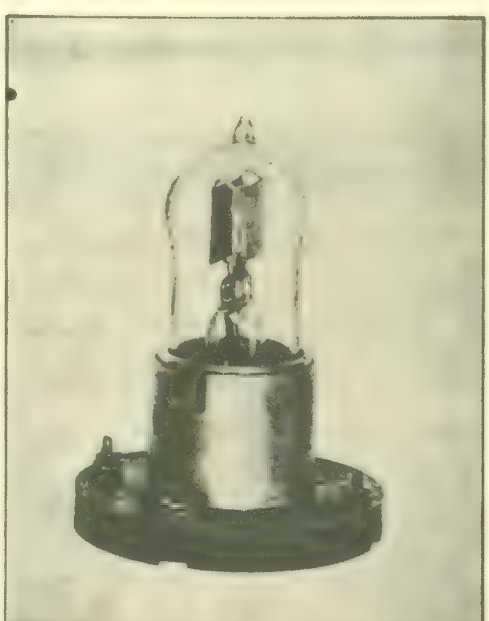

Fig. 24. A So-Called V.T.-21 and Its Socket, a Tube Which Has Been Much Used by the U. S. Signal Corps.

The Audion—Its Action and Some Applications

rent, telegraphic communication by conduction or leakage currents should be possible, using the audion as detector and amplifier. I venture to prophesy that within a few years the tall towers and the atmospheric disturbances which have for two decades been esteemed necessary evils in transoceanic wireless signalling, will be regarded with those sentiments which we now bestow upon the coherer and the spark.

But more than this. Signalling by conduction currents of relatively low frequency will soon be practiced thru the earth as well as water; and we will find the antennæ of the future thrust upside down, as into abandoned oil-well borings, and making contact with deep semi-conducting strata, at points separated by a few miles; the two inverted antennæ of such a transmitter connected by an overhead power transmission line containing the alternating current generator and signalling device; and a similar arrangement for receiving.

Then our wireless messages will go thru the earth's crust, or possibly by a more direct path, and not around the earth's surface, to be tangled up as at present with a bewildering snarl of static ravellings. The audion amplifier stands ready to lead us back to the simpler methods of Morse and Lindsay, meritorious methods long ago abandoned because of the lack of an electric ear of indefinitely great sensitiveness.

The future of radio signalling at sea lies with the telephone rather than the telegraph. The simplicity, the reliability with which the medium of an undampt wave-carrier, ideally suited for voice transmission, can now be had will rapidly limit the crudity and laboriousness of the Morse code signalling between ships. Yet today scarcely the dawn of this new epoch has been seen. Vessel owners are today almost as skeptical regarding the practicability and utility of the radiophone as we pioneers found them toward the wireless telegraph sixteen years ago!

In the future during fogs at sea a short-wave radio telephone will be used to prevent collisions, distances being determined (as well as direction) by conversation, whistled signal or bell and a calibrated stopwatch. This service will be quite independent of the long-range wireless signalling. The new radio has also a wide field of usefulness in telephoning between islands, thousands of which will never be linked by cable. Other useful fields await in sparsely peopled countries, between mines, oil wells, forest patrols, from express trains, etc. The future of aviation will be found linked with radio telephone, or a score of different purposes. Telephony by audion transmitter, receiver, and amplifier not only carries the complexes of human speech without distortion, but delivers them where human speech itself is impossible otherwise—amid the deafening motor and propeller noises of the airplane, from one to five miles above the earth.

Little imagination is required to depict new developments in radio telephone communication, all of which have lain fallow heretofore awaiting a simple lamp by which one can speak instead of read.

HISTORICAL STUDIES IN TELECOMMUNICATIONS

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The Electric Telegraph: An Historical Anthology. Edited, with an Introduction by George Shiers. 1977

The Telephone: An Historical Anthology. Edited by George Shiers with an Introduction by Elliot N. Sivowitch. 1977

The Development of Wireless To 1920. Edited by George Shiers with an Introduction by Elliot N. Sivowitch. 1977

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